UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

April 5, 1985

OFFICE OF
THE ADMINISTRATOR

Honorable Lee M. Thomas
Administrator
U. S. Environmental Protection Agency
401 M Street, S. W.
Washington, D. C. 20460

Dear Mr. Thomas:

The Science Advisory Board has completed its review of a number of scientific issues related to the assessment of the public health and environmental impacts associated with the incineration of hazardous wastes on land and at sea. The Board's review was carried out by its Environmental Effects, Transport and Fate Committee. The charge to the Committee included six major issues, including 1) the transfer of wastes; 2) combustion and incineration processes; 3) stack and plume sampling; 4) environmental transport and fate processes; 5) human health and environmental effects assessment; and 6) research needs.

The Committee has engaged in an extensive dialogue on these issues over the past year with EPA staff, officials of Federal and state agencies and members of the public. Each of these groups contributed scientific data to the Committee's inquiry and provided a valuable perspective on the interpretation of such data.

The Committee believes that hazardous waste incineration is a very important part of the Agency's strategy to properly manage and dispose of hazardous chemicals. It further believes that by acquiring additional information on a number of technical issues the Agency will enhance its capability to not only defend its incineration programs but also to enable the public to realize the benefits of this waste disposal technology. This will become especially true if, as anticipated, the program expands in future years.

The report concludes that the operation of both land and sea based hazardous waste incinerators has produced no adverse consequences to the public health or the environment. Considerable uncertainty surrounds the data that lead to this conclusion, however, and the Committee recommends a number of steps the Agency ought to undertake to reduce this uncertainty. These include fuller assessment of fugitive emissions from all phases of waste management and disposal processes; better characterization of incinerator emissions and effluents so that the identity and quantity of chemicals released into the environment can be estimated; determination of emissions under all incinerator operating conditions; and development of a coordinated research strategy involving both laboratory toxicity studies and field assessments to address both the possibility of short-term and long-term public health and environmental effects.

We believe the report should prove useful to you, other Agency officials and the general public in promoting a wider understanding of the scientific data needs and the public policy choices that have to be addressed in improving the nation's ability to properly dispose of hazardous wastes. The Board appreciates the opportunity to present its views and stands ready to provide any additional assistance that is needed by the Agency. We request that the Agency respond to our report.

Sincerely,

Rolf Hartung

Rolf Hartung, Chairman
Environmental Effects, Transport
and Fate Committee
Science Advisory Board

Norton Nelson

Norton Nelson, Chairman
Executive Committee
Science Advisory Board

REPORT

on the

INCINERATION OF LIQUID HAZARDOUS WASTES

by the

ENVIRONMENTAL EFFECTS, TRANSPORT AND FATE COMMITTEE

SCIENCE ADVISORY BOARD

U. S. ENVIRONMENTAL PROTECTION AGENCY

April 1985

NOTICE

The following Report has been written as part of the activities of the Environmental Protection Agency's Congressionally established Science Advisory Board. The Board consists of independent scientists and engineers who provide scientific advice to the EPA Administrator on a number of issues before the Agency. The Board provides a balanced, independent and expert assessment of the scientific issues it reviews. The contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency.

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PREFACE

This is the final report of the Environmental Effects, Transport and Fate Committee (EETFC) of the EPA's Science Advisory Board (SAB) on the review of scientific issues related to the public health and environmental impacts associated with the incineration of liquid hazardous wastes at sea and on land. In this review the EETFC was assisted by representatives of the SAB's Environmental Engineering Committee. Committee members carried out their review at the direction of the Executive Committee of the SAB to which they report.

On October 13, 1983, Administrator William D. Ruckelshaus requested that the Executive Committee assist the Agency in its scientific assessment of incineration at sea. On April 12, 1984 Deputy Administrator Alvin L. Alm requested that the Executive Committee expand the scope of the review to include an examination of public health and environmental impacts related to land incineration of hazardous wastes and to make a generic comparison of the major scientific issues between incineration at sea and on land. The Executive Committee accepted both of these requests and referred them to the Environmental Effects, Transport and Fate Committee. (For a list of Members and Consultants serving on the Committee, see Appendix I.)

The EETFC began its review in February 1984 with a series of briefings from Agency staff, subsequently made site visits to EPA laboratories and regional offices, commercially operating incinerators and incinerator ships under construction, and received public input at its open meetings. The Committee is acutely aware of the need to provide information and advice to EPA policy makers to meet the exigencies of near-term decisions and to accumulate knowledge over the long-term to provide an improved understanding of the relationship between emissions and health and environmental effects from incineration activities. The Committee's recommendations are aimed at strengthening the Agency's capability to meet both of these objectives.

A. Charge to the Committee

After discussions with EPA staff, the Committee identified six areas to evaluate the incineration of hazardous wastes at sea and on land. The Committee set out to determine whether the Agency had considered and interpreted the appropriate data for each area in a scientifically adequate manner. These areas include the following:

1) Transfer of wastes.

What are the various handling, loading, transportation, and routing problems? What potentials exist for collisions, explosions, and spills? Should the Agency develop worst-case scenarios to evaluate the potential impacts of accidental discharges?

2) Combustion and Incineration Processes.

Is the efficiency of destruction properly addressed? Are the quantitative and qualitative characteristics of the combustion products released into the environment appropriately evaluated?

3) Stack and Plume Sampling.

What specialized sampling protocols are needed to adequately charaterize representative emissions from the stacks exhaust and plume?

4) Environmental Transport and Fate Processes.

How should known and modeled atmospheric and oceanic circulations at the burn sites be considered? Are potential food web influences adequately assessed?

5) Biological Effects.

Do data on incineration efficiency, composition of emission products, and environmental transport and fate processes provide an adequate basis for evaluating biological effects? Have other issues, such as the bioavailability and toxicity of emitted compounds, been adequately addressed?

6) Research Needs.

What key scientific issues should the Agency address in its incineration research strategy?

B. Key Assumptions Guiding the Committee's Review

Because of the complexity of the scientific issues under review and the time constraints for carrying out the review, the Committee has restricted and simplified the scope of it's work in a number of important ways. The following considerations which guided the Committee's work reflect these limitations:

o The Committee concurs with the Agency's position that the destruction of wastes is an important activity and that, in many instances, such destruction is preferable to their storage. The Committee considers landfilling and deep well injection of toxic wastes, for example, to constitute forms of storage and not toxic waste disposal.

o The Committee approached the scientific comparison of hazardous waste incineration issues at sea and on land by examining the entire path of liquid hazardous chemicals from the point of generation through transportation, incineration, and ultimate transport, fate and effects of residues. The Committee is, however, aware of many alternative methods of waste disposal, including other types of thermal degradation, chemical detoxification, biological degradation, and solidification, which were not within the scope of its review.

o The Committee did not undertake any economic analyses of the various waste management and disposal processes, nor did it conduct any comparative cost-benefit analyses.

o The Committee recognizes that EPA's efforts to implement programs to incinerate liquid hazardous wastes are in various stages of development. For example, regulations to define the conditions for incinerating such wastes on land have already been promulgated under the authority of the Resource Conservation and Recovery Act (RCRA) and under the Toxic Substances Control Act (TSCA) for Polychlorinated Biphenyls (PCBs). The Agency, however, is currently taking public comment on its proposed regulations to govern the incineration of liquid hazardous wastes at sea under the auspices of the Marine Protection Research and Sanctuaries Act.

o The Committee is aware that its comments concerning at sea incineration have implications for regulations already in place for the burning of wastes on land. There are always areas in which understanding can be improved, and any scientific review of a technology or procedure runs the risk of seeming to be negative by virtue of asking new questions. In view of this situation, the Committee would like to make several observations:

1) Incineration is a valuable and potentially safe means for disposing of hazardous chemicals, and EPA has made progress in developing an appropriate regulatory strategy. However, this Committee has been asked to address the shortcomings and needs of this program, and its comments should be considered in the light of what probably is, in fact, a valuable technology.

2) The Committee's comments, both positive and negative, should be interpreted by the Agency and the public as a desire to strengthen already existing incineration programs rather than to discontinue what is already in place.

3) The state of scientific knowledge for many of the issues reviewed by the Committee is such that although definitive answers to many policy questions are not possible, the Agency needs to make policy and permitting decisions in the face of uncertainties, given the limitations of alternative technologies and facilities. It is also the EPA's responsibility, however, to address and to reduce the levels of uncertainty associated with this activity by carrying out and/or sponsoring the needed research. The Committee also encourages the Agency to use the permitting process in such a way as to increase the knowledge base on monitoring and possibly other issues.

4) The Committee has limited its review to the assessment of human health and environmental risks from the incineration of liquid hazardous wastes. It is the Agency's responsibility to choose among existing technological alternatives to minimize such risks in an acceptable manner. For example, the Agency needs to decide whether land based and ocean based incineration regulations should be equally stringent.

5) The Committee believes that many of the conclusions and recommendations derived from this review are also applicable to other combustion processes, such as those which occur in fossil fuel power plants and home heating units.

RECOMMENDATION 2:

THE EMISSIONS AND EFFLUENTS OF HAZARDOUS WASTE INCINERATORS NEED TO BE ANALYZED IN SUCH A WAY THAT THE IDENTITY AND QUANTITY OF THE CHEMICALS RELEASED INTO THE ENVIRONMENT, INCLUDING THEIR PHYSICAL FORM, CAN BE ESTIMATED. THE AGENCY SHOULD DEVELOP A REVISED DESTRUCTION EFFICIENCY PARADIGM SO THAT ITS ASSESSMENT OF INCINERATION PERFORMANCE CAN ACCOUNT FOR THE VARIABILITY OF EMISSIONS AND EFFLUENTS.

Conclusion 3:

Research on the performance of incinerators has occurred only under optimal burn conditions and sampling has, on occasion, been discontinued during upset* conditions which take place with unknown frequency. Even relatively short-term operation of incinerators in upset conditions can greatly increase the total incinerator emitted loadings to the environment.

RECOMMENDATION 3:

THE DETERMINATION OF THE ACTUAL EMISSIONS AND EFFLUENTS OF AN INCINERATOR SHOULD RESULT FROM AN ASSESSMENT OF THE TOTAL MASS LOADINGS TO THE ENVIRONMENT UNDER ALL OPERATING CONDITIONS.

Conclusion 4:

The existing analytical data for emissions from hazardous waste incinerators have serious limitations. Among the major problems are the limited number of chemicals selected for analysis and the fact that the analytical methodologies have not been validated either for the conditions of the test or for the complex mixtures which exist in incinerator emissions. As a result, there exist no relatively complete or reliable analyses of mass emissions from either land or sea based incinerators on which to base subsequent estimates of the potential for environmental exposures. These analytical problems are particularly difficult to solve for incinerator stacks with very high exit temperatures.

RECOMMENDATION 4:

SAMPLING AND ANALYTICAL METHODOLOGIES SHOULD BE VALIDATED FOR MEASUREMENTS OF EMISSIONS FROM HAZARDOUS WASTE INCINERATORS.

Conclusion 5:

The identification of optimal locations for incineration facilities can be greatly improved through the proper use of modeling and simulations. Through the use of such analytical techniques, the Agency could evaluate local, site-specific effects on the dispersion and subsequent exposures from incinerator emissions. Siting evaluations could incorporate temporal meteorological variations as well as micro-meteorological differences among sites. Knowledge of site-specific atmospheric dispersion conditions is also an important aspect of an emergency response modeling system. Real time emergency response models should utilize representative ambient measurements and site-specific source characteristics to provide planners

* As used in this report, the term upset condition refers to the operation of an hazardous waste incinerator under less than optimal performance.

SYNOPSIS

This synopsis contains the major conclusions and recommendations developed by the Environmental Effects, Transport and Fate Committee which apply to liquid hazardous waste incineration both at sea and on land. The Committe generated many other conclusions and recommendations, but these appear only in the body of the report because they deal with more specific rather than generic aspects of the incineration of hazardous wastes. The reader is cautioned against drawing his/her conclusions after reading only the synopsis. Because of the complexity of the issues, the report should be read in its entirety.

The ordering of the conclusions and recommendations follows the path of the waste and its daughter products from generator to final receptor. This ordering of recommendations does not imply a prioritization but rather reflects the path of the Committee's analytical thought processes. The Committee believes that its most important conclusions and recommendations relate to the ultimate impacts incineration practices have on human health and the environment (see conclusions and recommendations 11 and 12).

Major Conclusions and Recommendations

Conclusion 1:

Nearly all types of hazardous waste management and disposal involve the collection, temporary storage, pumping and transport of the wastes. Accidental spills and fugitive emissions* can occur during any of these processes. Based upon presently available data, the Committee cannot assess the full magnitude of this problem, but it acknowledges a possibility that fugitive emissions and accidental spills may release as much or more toxic material to the environment than the direct emissions from incomplete waste incineration.

RECOMMENDATION 1:

THE AGENCY SHOULD ASSESS THE ENVIRONMENTAL RELEASES OF FUGITIVE EMISSIONS OF CHEMICAL WASTES AND WASTE-DERIVED MATERIALS FROM ALL PHASES OF EACH WASTE MANAGEMENT AND DISPOSAL PROCESS, INCLUDING THOSE NOT ADDRESSED IN THIS REPORT. INSOFAR AS INCINERATION INVOLVES UNIQUE EXPOSURES OR EVENTS, THESE SHOULD BE SPECIFIED.

Conclusion 2:

The Agency adopted the concept of destruction efficiency to monitor whether or not incineration destroyed liquid hazardous wastes. This approach emphasizes the identification of several preselected compounds in the waste and does not fully address either partial oxidation or chemical recombinations which may create new toxic compounds. To date, only a very small portion of the compounds found in emissions from incinerators has been identified qualitatively or quantitatively. As a consequence, the concept of destruction efficiency (while valid for comparing the relative operating performance of incinerators) does not completely address the problem of what is emitted from the incinerator stack and does not, therefore, constitute a reliable basis for developing exposure assessments.

* Fugitive emissions in this report refer to instances of uncontrolled releases from valves, inadvertent minor ruptures in containers or pipes, and small spills that occur during waste storage or transfer operations. The Committee does not apply this term to major accidents, collisions, explosions or spills.

THE ROLE OF MICRO-LAYERS IN THE TRANSPORT AND CONCENTRATION OF EMITTED CHEMICALS INTO THE BIOSPHERE SHOULD BE INCORPORATED INTO THE AGENCY'S ANALYSIS OF ENVIRONMENTAL IMPACTS OF HAZARDOUS WASTE INCINERATION.

MODELING OF INTERPHASE TRANSPORT AND FATE OF CHEMICALS EMITTED FROM INCINERATORS SHOULD BE COUPLED WITH SOME FIELD VALIDATIONS.

Conclusion 7:

Exposures of organisms to chemicals originating from liquid hazardous waste incinerators on land and at sea take place through various pathways which differ according to transport processes and the habits of the organisms involved. Such exposure pathways will certainly include absorption through lungs or gills, skin, and the food web. In addition, the mobilization of organic compounds from sediments and the entrainment of settled particles constitute transport and fate pathways. The exposures to organisms will vary over time and in the dose attributable to each chemical. The relative proportions of chemicals in the mixture to which organisms are actually exposed is likely to differ from initial incinerator emissions because of the differential influences of transport, phase distribution, and chemical reaction dynamics on the individually emitted chemicals. The accurate determination of such exposures, which need to take these variables into account, is thus very difficult. The Agency has made only limited efforts to assess such exposures and these suffer from various inadequacies because they resulted from either individual judgments or computer models without adequate laboratory or field verification.

RECOMMENDATION 7:

THE EVALUATION OF EXPOSURE DURATIONS AND CONCENTRATIONS SHOULD BE BASED ON BOTH A DETAILED ASSESSMENT OF ENVIRONMENTAL TRANSPORT PROCESSES AND THE HABITS OF THE EXPOSED ORGANISMS IN BOTH AQUATIC AND TERRESTRIAL ENVIRONMENTS. THE ROLE OF FOOD WEBS IN EVALUATING EXPOSURES REQUIRES PARTICULAR ATTENTION.

Conclusion 8:

It is difficult to associate the burning of hazardous wastes with observed changes in the terrestrial environment because many land based incinerators are sited in highly industrialized areas which have other combustion sources emitting similar compounds. EPA, however, has not made the fullest use of existing modeling techniques to evaluate the transport, fate and effects of incinerator products in terrestrial systems. In addition, currently available data for evaluating the environmental effects of incineration on terrestrial systems are inadequate. Thus, subsequent Agency exposure assessments to biota and humans are unreliable.

RECOMMENDATION 8:

THE TRANSPORT AND FATE OF INCINERATION PRODUCTS IN TERRESTRIAL ECOSYSTEMS NEEDS TO BE EVALUATED BY STATE-OF-THE-ART FIELD MONITORING IN CONJUNCTION WITH IMPROVED SIMULATIONS.

with reliable estimates of transport patterns, dilution, transformation features and deposition of released materials.

RECOMMENDATION 5:

EPA SHOULD EVALUATE THE DEGREE TO WHICH LOCAL METEOROLOGICAL CONDITIONS CAN MAXIMIZE ATMOSPHERIC DILUTION TO AVOID EXCESSIVE AMBIENT CONCENTRATIONS OF INCINERATOR EMISSIONS. THE AGENCY SHOULD ALSO INCLUDE REAL TIME SITE-SPECIFIC ATMOSPHERIC DISPERSION SIMULATION MODELS AS PART OF COMPREHENSIVE EMERGENCY RESPONSE SYSTEMS FOR ALL MAJOR HAZARDOUS WASTE INCINERATION FACILITIES.

Conclusion 6:

The Committee found that the Agency's evaluations of the transport and fate of emissions, while appropriately emphasizing the significance of the dilution of pollutants, have not sufficiently addressed mechanisms in the environment which would result in the concentration of emission products. Knowledge of such mechanisms is important to a fuller understanding of pollutant transport and fate even though the general picture is one of dilution of the emitted compounds.

The dynamics of atmospheric and aquatic transport processes will largely influence which segments of the biosphere are impacted by the emissions from chemical waste incineration. Within these processes, various mechanisms are likely to prominently influence the concentrations affecting biota. These mechanisms include: a) phase separation and chemical distribution between phases; b) interphase transport at air/water, air/solid, air/biota, water/solid, water/biota and solid/biota interfaces, and c) photo- and biochemically stimulated reactions involving the incinerator emissions after they leave the stack. Surface micro-layers (i.e., sea slicks) may play significant roles in the concentration of chemicals in some species.

These transport processes are time dependent and exhibit both short-term and long-term variability and trends. Such temporal changes should influence the selection of the most appropriate averaging time for use in the analysis of potential effects of liquid waste incineration.

It is possible to use simulation models effectively to evaluate many aspects of the environmental transport and fate of emitted chemicals. However, such simulations often have significant limitations which were not always recognized by the Agency. Such limitations can become significant when several smaller simulation models are linked into large scale simulations. The results from these large scale simulations are unconvincing, especially when they are not supported by some field validations.

RECOMMENDATION 6:

THE DYNAMICS OF ENVIRONMENTAL TRANSPORT, INCLUDING CHEMICAL DISTRIBUTION BETWEEN PHASES, AND INTERPHASE MASS TRANSPORT, SHOULD BE EVALUATED IN A WAY THAT IS USEFUL FOR EXPOSURE ASSESSMENT.

Chapter 1

INTRODUCTION

During the past year the Environmental Effects, Transport and Fate Committee of the Science Advisory Board has investigated the incineration of liquid hazardous wastes and the potential human health and environmental effects of incineration products. The Committee has not carried out a detailed comparative assessment of potential effects from other combustion activities, such as the burning of fossil fuels or wood, nor has it evaluated the incineration of other wastes such as those generated by hospitals or municipalities. The quantities of materials combusted, under often partially or uncontrolled conditions, in these other processes are much greater than those involved in the incineration of liquid hazardous wastes. The Committee is not aware of comparative data of the potential risks from these various fuels and wastes prior to combustion and the consequent potential risks after combustion.

The evaluation of the incineration of liquid hazardous wastes on land and at sea was a much more complex project than originally anticipated. A large amount of source materials which dealt with the incineration of these wastes exists. (The list of source materials consulted is presented in Appendix III.) The Committee expended considerable effort to collect and analyze the information that eventually formed the basis of its conclusions and recommendations. A major difficulty resulted from the fact that the Agency has no single or even coordinated repository of the relevant information. Therefore, the Committee had to collect this information piecemeal from the Office of Water, Office of Solid Waste, Office of Policy, Planning and Evaluation, Office of Research and Development, EPA Regional Offices in Dallas and Chicago, transcripts of EPA hearings, and occasionally from reports originating outside of the Agency. New communications were still found or volunteered by EPA very late in the development of the Committee's report. Even though the Committee perused and/or studied in detail an estimated hundred pounds of materials, it seems unlikely that it has identified every document relevant to this scientific review. We believe, however, that the information obtained is representative of the available scientific data base for understanding the issues discussed in this report and for supporting the Committee's conclusions and recommendations.

The Agency has studied and managed programs for incinerating hazardous wastes for some time. The various EPA programs have merit in that they offered a solution to several hazardous waste problems. The Agency's approach to hazardous waste incineration in many cases emphasized the engineering aspects of the problem of destroying wastes. In the course of the rapid development of incineration technologies, it appears that inadequate resources were devoted to a holistic and scientific review of these technologies regarding their environmental impacts and acceptability. The program depended heavily on concepts of "destruction efficiency," and

Conclusion 9:

The toxicities of emissions and effluents from land based and ocean based incinerators are largely unknown.

RECOMMENDATION 9:

THE TOXICITIES OF REPRESENTATIVE EMISSIONS AND EFFLUENTS FROM INCINERATORS SHOULD BE TESTED, AT A MINIMUM, ON SENSITIVE LIFE STAGES OF REPRESENTATIVE AQUATIC AND TERRESTRIAL VERTEBRATES, INVERTEBRATES, AND PLANTS OF MAJOR ECOLOGICAL IMPORTANCE.

Conclusion 10:

The assessment of biological effects of incineration products is a very complex undertaking. The data needed for assessing effects will not result from an exclusive reliance on laboratory studies, partial field studies, or complex field studies alone.

RECOMMENDATION 10:

THE ASSESSMENT OF THE POTENTIAL EFFECTS OF INCINERATION PRODUCTS REQUIRES A COORDINATED APPROACH INVOLVING BOTH LABORATORY TOXICITY STUDIES AND FIELD ASSESSMENTS. THESE INVESTIGATIONS NEED TO BE COUPLED IN A RESEARCH STRATEGY WHICH ADDRESSES BOTH SHORT-TERM AND LONG-TERM EFFECTS.

Conclusion 11:

The Committee found no documentation that the operation of liquid hazardous waste incinerators on land or at sea has produced acute adverse ecological effects. However, monitoring programs used to date were few and narrow in scope.

RECOMMENDATION 11:

APPROPRIATELY DESIGNED FIELD STUDIES ARE NEEDED TO PROVIDE ASSURANCE THAT THE LONG-TERM OPERATION OF INCINERATORS DOES NOT PRODUCE SIGNIFICANT ADVERSE EFFECTS TO THE ENVIRONMENT.

Conclusion 12:

The Committee found no documentation that the operation of liquid hazardous waste incinerators on land or at sea has produced acute adverse effects to public health. However, monitoring programs used to date were few and narrow in scope.

Recommendation 12:

EPA should evaluate the possible long-term consequences to human health of a continuing program of hazardous waste incineration.

"destruction and removal efficiency," which did not sufficiently account for the mass of partially destroyed wastes and the mass of compounds newly synthesized during the combustion process. The existence of these conditions does not necessarily mean that the incineration of liquid hazardous wastes is environmentally unacceptable, or that destruction efficiency is not a logical first step in evaluating incinerator performance, but the Committee believes that the existing base of information is insufficient to make a definitive statement about its environmental impacts over time.

In summary, the task of adequately evaluating the potential impacts of emissions from liquid hazardous waste incinerators on land or at sea is difficult because, while large amounts of source materials exist, they oftentimes do not address the issues raised during the Committee's review nor are they equal for the two environments. In addition, exposures to incineration related pollutants are not directly comparable between media. Different organisms, for example, exhibit different types of effects as the result of such exposures. Whether these effects occur below our detection capability or whether they will prove to be more significant due to a continuing incineration program cannot be stated with much certainty at this time. The Agency should consider these factors within the context of evaluating the full range of waste management and disposal alternatives which may produce exposures and effects.

Conclusion:

The programs for incinerating liquid hazardous wastes on land and at sea, and the destruction of other hazardous wastes by incineration, present the Agency with risk assessment and risk management issues that include engineering, environmental monitoring, residue management, and estimation of the effects on humans and other biota. Because these issues do not fall neatly within the boundaries of its current and historical organizational structure, the Agency continues to experience difficulties both in assessing and managing hazardous waste incineration programs. In general, the Agency did not assess a number of scientific issues relating to the incineration of liquid hazardous wastes, and addressed in this report, until its programs were either in later stages of development or already implemented.

Chapter 2

PROBLEMS ENCOUNTERED IN STORAGE, TRANSFERS AND TRANSPORTATION OF LIQUID HAZARDOUS WASTES

Much of the public concern about storage, transportation and transfers of toxic chemicals is directed toward the problem of exposures resulting from uncontrolled leaks and spills. The Committee believes the Agency should take steps to further minimize the occurrence of leaks and spills and initiate the preparation of emergency response plans to anticipate such events. Such plans should address the most probable emergency situations and require the involvement of trained personnel to execute the plans, perform periodic drills, and provide for necessary equipment and other resources. Typically, an emergency plan will need to consider the probability of chemical spills, fires and explosions, atmospheric dispersion and exposures of chemicals, and incidences of poisonings and injuries. These plans should also include the development of population evacuation procedures.

In connection with the problem of incineration at sea, the Committee reviewed background literature pertaining to a pending request for burning PCB wastes stored at Emile, Alabama. The plan for transporting PCB wastes from Emile to Mobile, Alabama for subsequent incineration at sea did not appear to address all these issues raised in the preceding paragraph. In addition, it failed to address problems associated with the handling of wastes at Emile. The Committee did not have access to a similar plan for a land based incinerator for timely review. Also, there appears to be no document which explicitly defines the roles of the EPA and the Department of Transportation with regard to any overlapping responsibilities for implementing the Resource Conservation and Recovery Act (RCRA) and the Hazardous Materials Transport Act (HMTA).

A potential exists for environmental and human exposures as chemicals are removed from storage containers at the generator site, moved to transportation vehicles, shipped to the incinerator, and moved about within the incineration facility. For ocean incineration, where the incinerator is mobile, an additional chance for exposure exists as the incinerator ship leaves port and travels to the burn area.

Exposures can result from three principal events. These include:

1. Fugitive emissions from tanks and vessels where the toxic chemicals are stored. These emissions are likely to be higher when chemical transfers occur between storage containers. Common sources of fugitive emissions include leaks around pump packings and through tank ventilation fittings.

2. Spills during transfer to and from tanks and transportation vessels. Faulty couplings between transfer lines and storage tanks, and spills during coupling activities are important causes of exposure. Inattentive supervision of loading operations leading to spills by overflow can also contribute to fugitive emissions.

3. Spills can occur during transportation because of fire, explosion or damage to the transport vehicle resulting from a collision.

As with many other aspects of the toxic waste problem, limited information exists regarding the handling and transportation of these wastes. A brief summary of the data made available to the Committee is presented below.

A. Nature and Frequency of Accidental Spills

As required by the 1980 Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and Section 311 of the Clean Water Act, EPA compiles information on reportable spills of ten pounds or more of material. The frequency of spills for PCBs, for example, in amounts over ten pounds is reported in Table I[1]:

Table I
Number of PCB Spills Over Ten Pounds, 1980 - 1983

1980	303
1981	381
1982	689
1983 (8 months)	569

[1] Personal telephone communication. John Riley, Chief of Response, Standards and Criteria Branch, Emergency Response Division, U. S. Environmental Protection Agency. July 25, 1984.

The Committee found no statistics on the quantity of spilled materials. During transportation, handlers treat all chemicals similar to gasoline and consider them as hazardous whether or not they are wastes. Federal regulations require that only flammable liquids be transported in special U. S. Department of Transportation (DOT) trucks. DOT, however, is not responsible for the environmental impacts associated with the transportation and handling of chemicals. The general public also seems not to be aware of how to report chemical spills.

B. Fugitive Emissions

The Agency should more fully estimate the quantity of fugitive emissions. Emission factors exist for hydrocarbon liquids and petroleum refinery equipment applications which have been applied to estimate emissions in toxic waste handling facilities, but this work needs to be validated.

At least two types of events related to transportation cause fugitive emissions. First, the decanting of small containers (and/or handling of leaking containers) into trucks or rail tankers leads to releases. Second, fugitive emissions occur when chemicals held in tankers or trucks are decanted into the storage tank farms at the incinerator site or at dockside for at sea incineration. Additional emissions from lines, pumps, and other sources are released in the lines between tank farm storage and incinerators. Good housekeeping practices and frequent inspections will reduce these fugitive emissions. The levels of fugitive emissions under good housekeeping practices should be estimated and compared with emissions from incinerator stacks to better attribute the source of human and environmental exposures.

Technical flaws, however, exist in certain types of incinerators which lead to higher levels of fugitive emissions. Specifically, rotary kiln incinerators, because they lack a positive seal between rotary drum and stationary parts, experience conditions of "puff back" whenever the kiln receives a sudden high thermal loading of chemicals. These loadings occur usually when feeding solid chemicals or sludges contained in drums into the incinerator. Although the kilns normally operate at negative pressure with respect to the environment, a positive pressure is produced in these instances which forces some of the chemicals in the kiln through the annular space between drum and stator into the environment. The level of emissions resulting from these design characteristics needs evaluating, and the technical flaws should be eliminated in cases where EPA determines that unacceptable emission levels exist.

ICF, Inc. has estimated release rates of chemicals from containers as a fraction of the container capacity and the distance they are shipped. Table 2 presents these data.

Table 2
Fractional Losses of Liquid Chemicals from Containers as a Function of Distance Transported*

	ONE WAY DISTANCE		
Container Type	14 MILES	25 MILES	250 MILES
Tanker	8×10^{-6}**	1×10^{-5}	3×10^{-5}
Steel Drum	3×10^{-4}	4×10^{-4}	9×10^{-4}
Open Metal Container	1×10^{-3}	1×10^{-3}	3×10^{-3}

** To obtain volume of chemicals lost, multiply fractional losses by the volume of the container.

Table 2 is based upon modeling techniques used by ICF, Inc.[1] which summarize estimates of fractions released for each container type for three shipment distances. These estimates result from incident, frequency and release rate data, information on shipment distance, truck volume and accident data. The Committee wishes to stress the point that Table II presents only theoretical data on chemical losses. There is a need for real world data to replace this table.

The Committee believes, as do other observers, that the possibility exists that, with current management practices, fugitive emissions from handling at the generator site, as well as transportation losses en route to the incinerator and in chemical waste storage areas surrounding certain incinerators may be as great or greater than the toxic chemicals emitted from the incinerators as a result of incomplete combustion.[2]

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[1] ICF, Inc. Report on the RCRA Risk-Cost Analysis Model Phase III, March 1, 1984.

[2] Abkowitze M.A. Eiger and S. Srinivasan. Assessing the Risks and Costs Associated with Truck Transport of Hazardous Wastes. Draft Final Report for the Office of Solid Waste of U.S. EPA, Washington, DC 1984.

Systems Applications, Inc. Human Exposure to Atmospheric Concentrations of Selected Chemicals. Prepared Under EPA Contract 68-02-3066 for the Office of Air Quality Planning and Standards, 1983.

* The Committee assumes that volatilization accounts for some portion of these losses.

C. Handling Procedures

The Federal government has not specified procedures to handle toxic chemical wastes, nor has it evaluated alternative procedures to determine which are most effective in minimizing spills and fugitive emissions. The Committee was informed that the Department of Defense decanted and transferred Agent Orange and DDT wastes to the vessel Vulcanus I under controlled conditions at the Navy Base at Gulfport, Mississippi,[1] but it could not establish what procedures private industry uses for handling similar wastes.

Issues relating to the incidence of leaks and spills during transport and storage operations are similar for incineration on land and at sea until the moment the chemicals are loaded aboard the incinerator ship. At this point the causes and magnitude of fugitive emissions and spills may diverge. The complex motions of the ship on an open sea may increase the problem of stable operation of the onboard incinerator.

The risks of exposure to human and non-human populations are associated with factors such as the location of the sources of chemical wastes, the siting of incinerator facilities, and to the mass and composition of chemicals to be incinerated. The greater the traffic between a source and an incinerator, the more likely is the incidence of spills. The Agency should prepare or direct the preparation of a statistical profile of spills, based upon historical data, to assess the probability of various exposure scenarios. This analysis should include a discussion of optimum transport methods. If shipment sizes are large, the number of shipments and, consequently, the number of spills are reduced; however, the amount of material released to the biosphere increases in the event of a spill. Theoretical emission factors of storage plant equipment should be used to estimate fugitive releases; in addition, actual toxic waste storage facilities should be visited to determine plant component emission factors. The protocol to determine the likelihood of exposure resulting from incineration should consider factors such as human population density at the waste source, along the route, and at the site of the incinerator; and fugitive emissions and potential spills at the source, the waste storage plant, during transit to the incineration site, and at the incinerator waste storage plant.

These factors, in turn, will be influenced by the total annual amount of material incinerated in a region and the capacity of transport vehicles. Available capacity determines the frequency of transport, which influences the likely number of spills and the mass emitted during spills. Estimates of the total emissions due to loading and unloading operations can then be specified. Once this step takes place the development of an exposure analysis which expresses the summation and

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[1] Personal telephone communication. Russel H. Wyer, Director, Hazardous Site Control Division, Office of Emergency and Remedial Response,

assessment of all likely emissions and the determination of the human populations exposed to the emissions can occur. Subsequently, Agency staff can evaluate the human health and environmental effects believed to occur from such exposures. The Committee believes that the above procedure can be formalized in a series of algorithms to conduct a systematic evaluation of exposure conditions.

Catastrophic accidents, especially near incineration sites where large quantities of liquid hazardous wastes are stored and burned, require the ability to mount rapid emergency responses. Since the major route for the initial movement of hazardous wastes during an accident is likely to be through the atmosphere, a real-time emergency response simulation capability should be developed to provide a site-specific analysis of the atmospheric transport and dispersion of toxic gases and particles released or evaporated into the air. The simulation model should have the capability of using local meteorological observations and objectively evaluating the effects of local topographic features on wind flow, and addressing factors such as plume rise and initial diffusion. The simulation model should be readily usable at all major incineration facilities and for all major transportation routes.

Conclusion:

Nearly all types of hazardous waste management and disposal involve the collection, temporary storage, pumping and transport of the wastes. Accidental spills and fugitive emissions can occur during any of these processes. Based upon presently available data, the Committee cannot assess the full magnitude of this problem but acknowledges a possibility that fugitive emissions and spills may release as much or more toxic material to the environment as the direct emissions from incomplete waste incineration.

RECOMMENDATION:

THE AGENCY SHOULD ASSESS THE ENVIRONMENTAL RELEASES OF FUGITIVE EMISSIONS OF CHEMICAL WASTES AND WASTE-DERIVED MATERIALS FROM ALL PHASES OF EACH WASTE MANAGEMENT AND DISPOSAL PROCESS, INCLUDING THOSE NOT ADDRESSED IN THIS REPORT. INSOFAR AS INCINERATION INVOLVES UNIQUE EXPOSURES OR EVENTS, THESE SHOULD BE SPECIFIED.

Conclusion:

The probabilities of the magnitude and duration of human and non-human population exposures to hazardous chemicals are influenced by many factors, such as the occurrence of fugitive emissions, which could be minimized by changed operational procedures for incineration activities. Examples of such procedures include the use of traps on storage containers and low leakage interconnects between storage tanks and transport vehicles.

RECOMMENDATION:

EPA SHOULD EVALUATE THE POSSIBILITY OF ADOPTING ALTERNATIVE MANAGERIAL PROCEDURES THAT COULD REDUCE THE PROBABILITIES OF CHEMICAL SPILLS, THE MAGNITUDE OF FUGITIVE EMISSIONS, AND THEIR POTENTIAL EFFECTS.

Conclusion:

Based upon the data submitted for its review and observations made during site visits of operating facilities, the Committee is concerned, in the absence of qualified on-site inspectors, about the reliability of operating large-scale land based incinerators, especially for critical chemical burns (e.g., dioxins, PCBs, dibenzofurans, etc.).

RECOMMENDATION:

THE AGENCY SHOULD SERIOUSLY CONSIDER THE USE OF ON-SITE INSPECTORS FOR AT LEAST LARGE VOLUME, HIGHLY HAZARDOUS CHEMICAL INCINERATIONS ON LAND. THIS IDEA IS SIMILAR TO THE SHIP-BOARD RIDER CONCEPT EMPLOYED FOR INCINERATION AT SEA.

Conclusion:

Responses to accidental releases need to be rapid and objective and must be initiated with minimal lead time to avoid or minimize any adverse health impact on the surrounding populations. A knowledge of site-specific atmospheric transport conditions is an important element for an emergency response capability at major incineration sites, transfer points, and along major transportation routes.

RECOMMENDATION:

REAL-TIME, SITE-SPECIFIC ATMOSPHERIC TRANSPORT SIMULATION MODELS SHOULD BE AN INTEGRAL PART OF PLANNING EMERGENCY RESPONSES FOR INCINERATION PLANTS, AND TRANSPORT, STORAGE AND TRANSFER FACILITIES.

Chapter 3

PROBLEMS ASSOCIATED WITH HAZARDOUS WASTES INCINERATION PROCESSES

Incineration of toxic chemicals in the context of this report refers to high temperature oxidation of liquid hazardous wastes in specially designed incinerators. Due to time and resource constraints, the Committee did not examine in great detail non-oxidative high temperature destruction processes as a means of thermal destruction of toxic chemicals, although the high temperature pyrolysis methods may prove to be another promising chemical waste management approach.

Typically, the incinerators under discussion in this report operate between 900°C and 1,200°C and are fueled by the toxic chemicals with auxiliary heating supplied by a fuel oil or natural gas when burning chemicals with low heating values. Design gas phase residence times in the high temperature zones range from 0.2 seconds to several seconds.

The completeness of conversion of the incinerated wastes to carbon dioxide (CO_2), water (H_2O), hydrochloric acid (HCl) and carbon monoxide (CO) depend upon a complex interplay of chemical and physical variables including combustion temperatures, gas-phase mixing, waste atomization, and residence time in the combustion zone. Incinerators discussed in this report have the capability to burn a wide range of liquid hazardous wastes. Major attention has focused on the oxidation of halogenated hydrocarbons since these substances are relatively difficult to completely incinerate. The detailed pathways for the combustion reactions have not been defined, although a more complete understanding of the chemistry would undoubtedly provide significant information which would prove useful to enhance the design and operation of incinerators.

The destruction of complex halocarbons occurs in a sequence of reaction steps. These consist of bond scission creating chemical fragments which undergo further fragmentation and oxidation. The reaction times for the individual steps last on the order of milliseconds at typical incineration temperatures. The availability of hydroxyl (OH) radicals appears to promote the rate of decomposition of many hazardous compounds. Because chlorine serves as an OH radical scavenger, chlorocarbons have been used as fire retardants, thus slowing down oxidation rates. Chemicals with high chlorine to hydrogen ratios tend to soot readily. In general, the chlorocarbons must be burned with large quantities of excess air relative to hydrocarbons to prevent soot formation during combustion.

Ideally, all wastes entering the incinerator will eventually degrade into their simplest forms, e.g., CO_2, H_2O, HCl. Because none of these processes is 100% efficient, however, incomplete combustion of wastes, or the synthesis of new compounds due to recombination of molecular fragments outside of the combustion zone, complicates considerably the evaluation of the completeness of combustion.

In the case of the Vulcanus I and Vulcanus II incinerator vessels, operated by Chemical Waste Management, Inc., the residence time of components in the incinerator is about one second. Tests of land based incinerators have used residence times of less than 1 second to 6.5 seconds. Gas chromatogram analyses of stack gas samples collected from both land and sea based incinerators indicate that organic compounds are emitted. Whether these compounds are unburned portions of the original waste or the result of chemical recombinations is unknown. In either case, it is clear that substances other than CO_2, CO, H_2O and HCl exit the incinerator stack. The degree of destruction achieved is, therefore, imperfect.

Given the difficulties of analyzing all of the stack emissions, a completely detailed analysis may be impossible. The Agency chose to emphasize measurement of the disappearance of selected waste constituents as a means of testing the performance of incinerators and to use ratios of CO/CO_2 as indicators of incinerator performance. The Agency assumed that, by analyzing the waste to be burned and selecting an abundant component with a low heat of combustion, thereafter called a Principal Organic Hazardous Constituent (POHC), and monitoring the stack emissions for the POHC, one could determine the amount of destruction for other components with higher heats of combustion. In other words, by monitoring the feed and emissions for carefully selected compounds during trial burns and monitoring the levels of O_2 and CO in the gas, one could estimate the destruction efficiency (DE) for the total waste and estimate the operational performance of the incinertor.

The hypothesis of incinerability based upon relative heats of combuston is an approximation founded on thermodynamic assumptions. EPA has ranked organic compounds according to their heats of combustion based on the list of such compounds in Appendix VIII 40CFR Part 261. The Agency has published this list in its "Guidance Manual for Hazardous Waste Incinerator Permits." The list allows one to track a suitable POHC as incineration proceeds. The assumptions underlying the general applicability of the POHC concept for all compounds in the waste stream will be valid only if the kinetics of combustion and destruction for all the waste compounds are fast enough for the reactions to take place before the wastes exit the incinerator. The data collected during research and trial burns generally support the Agency's position that incinerators can be built and run under a set of optimal conditions so that the destruction efficiency for the selected POHCs can meet specified criteria of 99.99% to 99.9999% DE (for PCB's). Apparently, the Agency developed this approach as a policy choice to guide the development of regulations for land based incinerators. However, as long as the definition of destruction efficiency addresses only the disappearance of the parent POHC and does not take into account products of partial decomposition or products newly synthesized in the incineration process, the definition is limited in its ability to aid in the assessment of total emissions and subsequent assessments of environmental exposures.

The fact that numerous compounds have appeared in the emissions of liquid hazardous waste incinerators causes the Committee to question the assumption that a POHC can be used as a surrogate for the destruction of all other compounds in the waste. EPA is cognizant of this problem, for it has recognized an additional group of compounds which may be in the stack gas. These are called Products of Incomplete Combustion (PICs).

PICs are defined as compounds on the Appendix VIII list but present in the feed at levels of <100mg/l. By definition, compounds absent from the Appendix VIII list can be neither POHCs nor PICs. Therefore, they are seldom determined. It is possible that the aggregate of all compounds in the emissions, which are neither categorized as POHCs or as PICs, are more toxic and pose higher environmental risks than those listed. Data on the toxicities of combustion products relative to parent compounds are lacking.

A review of all documents supplied to the Committee that pertained to past monitoring of incineration events, as well as data requested from EPA officials, have failed to yield a single "complete" analysis of the identities and quantities of organics emitted from an incinerator stack. Even data on PICs in the emissions are extremely scarce. This view is supported by Trenholm (Trenholm et. al., November 1984) who stated that "...the data base for PICs from combustion of the complex matrices of organic constituents which currently are being fed to hazardous waste incinerators was virtually nonexistent before the Midwest Research Institute [Gorman, P. and K. P. Ananth, 1984] study".[1] In the MRI study, PICs were defined as compounds in the stack gas samples that appear in Appendix VIII and under 100 ppm in the feed. Twenty-nine PICs were identified. Travis et al. 1984, estimate that only 1% to 10% of the total hydrocarbon emissions were identified in the MRI study. Trenholm et. al. (1984) also present data on the amount of PICs emitted from the eight incinerators studied as a percent of the POHC input. This can be presented in the following equation:

$$\% = \frac{\text{PIC output (g/min)}}{\text{POHC input (g/min)}} \times 100$$

The various results range from 0.00029% to 0.012% with a mean of 0.0031% (Travis et. al., 1984). In the Trenholm et. al. (1984) study, the eight incinerator operators received advance notice of the visitation of EPA contract personnel so that operations at the facilities may have been at or near optimal performance. In addition, in one case when optimal operation was not achieved, the sampling probe was removed and reinserted after the situation was corrected. Therefore, one could logically assume that normal emissions often contain more PICs than reported.

Midwest Research Institute was requested by EPA to characterize more completely the organic emissions of one of the eight incinerators tested. Retrospective studies of this type are difficult to do since no quantitative standards were used during the actual chemical analyses; thus, any subsequent interpretation of the data for such unquantitated chemicals is

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[1] Letter from James L. Spigarelli to Timothy Oppelt regarding the characterization of organic chemical emissions from a selected hazardous waste incinerator, July 25, 1984.

somewhat speculative. The data retrieved were from gas chromatography-mass spectrometry (GC-MS) records. Even so, 53 compounds were observed of which 29 were POHCs. Total hydrocarbon emissions averaged 1900 ng/l in the stack gas; however, only 610 ng/l were identified by the GC-MS. Utilizing 1900 ng/l as the output term in the DE equation, the calculated DE is approximately 99.99%. This particular incinerator was a large rotary kiln with afterburner unit followed by water sprays, two packed beds and an ionizing wet scrubber. Without such an air pollution control system, it is very likely that the calculated DE would be less than 99.99%.

Based on the data of Trenholm et. al., EPA could approximate the chemical emissions from incinerators, but they remain only as approximations because the representativeness of the data is unknown. These estimates may be used to indicate whether or not to raise concern over the potential organic emissions from incinerators. In the case of an hypothetical incinerator ship, the following assumptions could be made:

A. Ship capacity $= 4.1 \times 10^3$ metric tons
$= 4.1 \times 10^6$ kg

B. Maximum permitted PCB concentrations = 35% in waste

C. Average % PIC output of POHC input = 0.0031% for 8 land based incinerators

D. Maximum % PIC output of POHC input = 0.021% for 8 land based incinerators

E. Only 1% of total emitted hydrocarbons detected

These assumptions form the basis for the following calculations:

A. Maximum amount of PCB input per burn
$(4.1 \times 10^6 \text{ kg/burn})\ (0.35) = 1.4 \times 10^6$ kg/burn

B. PIC output per burn assuming average land based incinerator performance:

$$(1.4 \times 10^6 \text{ kg/burn})\ (3.1 \times 10^{-5}) = 4.3 \times 10^1 \text{ kg/burn} = 43 \text{ kg/burn}$$

C. PIC output per burn assuming worst land based incinerator performance

$$(1.4 \times 10^6 \text{ kg/burn})\ (1.2 \times 10^{-4}) = 1.7 \times 10^2 \text{ kg/burn} = 170 \text{ kg/burn}$$

D. Unburned hydrocarbon output assuming only 1% of hydrocarbons detected

1. For average land based incinerator performance

$$(43 \text{ kg/burn})\ (10^2) = 4.3 \times 10^3 \text{ kg/burn}$$

2. For worst land based incinerator performance

(170 kg/burn) (102) = 1.7 x 104 kg/burn

The literature supplied to the Committee on the DEs or Destruction and Removal Efficiencies (DREs) of PCB burns claims 99.99% or 99.9999% efficiencies throughout. These statements rely solely on POHCs, as expressed in the following equation:

$$DE = \frac{POHC_{in} - POHC_{out}}{POHC_{in}} \times 100 > 99.99\%$$

If one substitutes the calculated unburned hydrocarbon output (for the worst noted land based incinerator performance and assuming that only 1% of the unburned hydrocarbons are detected) for the POHC output in the above formula, perhaps another approximation of the Total Destruction Efficiency (TDE) may be obtained in the form of:

$$\text{"TDE"} = \frac{POHC_{in} - \text{total organics}_{out}}{POHC_{in}} \times 100$$

$$\text{"TDE"} = \frac{1.4 \times 10^6 \text{ kg} - 1.7 \times 10^4 \text{ kg}}{1.4 \times 10^6 \text{kg}} \times 100$$

$$= 98.8\%$$

Even if other combustible material made up the remaining 65% of the feed stock and 4.1×10^6 kg were substituted for the POHC, the modified destruction efficiency as calculated above would achieve 99.6%. If the average land based incinerator performance, using data inputs received from EPA, is assumed with detection of only 1% of the unburned hydrocarbons, the resulting modified destruction efficiencies for the two POHC estimates (1.4×10^6 kg and 4.1×10^6 kg) would attain 99.7% and 99.9%, respectively. In any case, 99.99% destruction efficiency does not appear to be achieved if compounds other than POHCs in the stack gas are considered.

To further stress the importance of measuring more compounds in the stack gas than just POHCs and perhaps a few PICs, the Committee would like to comment on data included in two reports prepared by the Rollins Corporation. One report[1] measured total organics in stack samples (gas samples, GC-FID, no column) and found an average of 1.1 lbs/hr. emitted.

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[1] PCB incineration test made by Rollins Environmental Services, Deerpark, November 12-16, 1976. Submitted to Jim Sales, EPA Region 6, Dallas Texas.

The other report[1] which looked for PCBs, dibenzofurans and EPA priority chlorinated hydrocarbons in stack samples, found less than 6.10^{-5} lbs/hr of these compounds emitted--a difference of 4 to 5 orders of magnitude. Admittedly, the feed rates of the two incinerators would differ, but it is unlikely that they would vary by this amount.

It is apparent that even with the uncertainties related to sampling efficiencies and inadequate chemical analyses, as much as 1% of the mass of waste feed could exit an incinerator as compounds other than CO_2, CO, H_2O and HCl. Without a thorough quantitative and qualitative analysis of these compounds, reliable estimates of their transport, their fates, and ultimately their human health and environmental impacts appear impossible. The Committee believes that relying on destruction efficiencies, as presently defined, to estimate the quantity and quality of all generated incinerator emissions is scientifically inadequate.

When the time varying nature of the incinerator performance is considered, DE as previously computed does not reflect the consequences of flame outs or other process upsets. Assuming a destruction efficiency of 99.9999% for an incinerator ship, a 10 second flame out could increase PCB emissions five-fold, assuming that the 10 second feed is vaporized and undestructed materials leave the stack. However, assuming a destruction efficiency of 99.99%, the effect of a ten second flame out may increase PCB emissions by 5 percent. In other words, two 10 second flame outs are equivalent to reducing the average DE from 99.9999% to 99.99%. These failure estimates are probably exaggerated, if the incinerator can maintain sufficiently elevated temperatures and other conditions to permit at least some destruction of the PCBs. The reader is cautioned that these calculations are hypothetical, but they served as illustrations to support the viewpoint that the higher the target destruction efficiencies, the more sensitive the entire system is to the effects of temporary upsets.

Comparison of Land Based and At Sea Incinerators

The Committee has observed the following differences between incinerators operating at sea and on land:

1. Incinerators on land tend to operate at lower temperatures and have longer residence times than incinerators at sea. Land based units may also be designed to operate on toxic chemical sludges as well as toxic liquids and, consequently, they may be segmented into a volatilization chamber and an afterburner.

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[1] Determination of polychlorinated dibenzo-p-dioxins, dibenzo-furans, and biphenyls in stack effluents and other samples from PCB incineration test at Deer Park, Texas and Insco, El Dorado, Arkansas, February 15, 1981. Submitted to James Sales, EPA Region 6, Dallas, Texas.

2. Existing incinerators at sea operate without scrubbers and, therefore, emit acid mists.

Some new ocean incineration vessels under construction are designed to use sea water for scrubbing or quenching. This scrub water will entrain some combustion products and have the potential to form saturated solutions of hydrocarbons in water. If the scrub water is returned to the ocean, it will remain at the surface because is it warmer than the ambient sea water. Exposures to surface dwelling marine organisms (neuston) will occur at much higher concentrations of combustion products than through transfer of these products from the plume to the water surface. However, these comments may not apply to all ocean based incinerator designs. In addition, the potential impact of combustion products from these vessels on aquatic biota may be easier to assess under controlled conditions in the laboratory.

Scrubber waters from land based incinerators also contain hazardous materials which must be disposed of in an environmentally acceptable manner. In at least one case, the Committee observed that scrubber water was discharged to the local sewer system; ultimately, some of the materials might enter local waterways.

3. Land-based incinerators operate on a stable base while ocean incinerators may operate on rolling and pitching seas. Sloshing of liquids in partially filled vessels can create surges in the operation of pumps, meters, and the incinerator, and may contribute to the possibility of operational upsets.

The Agency has not characterized the differences among various incineration technologies at sea and on land to assess the expected differences they may cause in incinerator performance. It should undertake such a comparison to complete a comparative risk analysis between the two technologies.

Conclusion:

To monitor whether or not liquid hazardous wastes were destroyed in the incineration process, the Agency adopted the concept of destruction efficiency. This approach emphasizes the elimination of several pre-selected compounds in the waste and does not fully address either partial oxidation or chemical recombinations, either of which may create new toxic compounds in the incineration process. To date, only a very small portion of the compounds found in emissions from incinerators has been identified qualitatively or quantitatively. As a consequence, the Committee finds the concept of destruction efficiency used by the Agency to be incomplete and not useful for subsequent exposure assessments.

RECOMMENDATION:

THE EMISSIONS AND EFFLUENTS OF HAZARDOUS WASTE INCINERATORS NEED TO BE ANALYZED IN SUCH A WAY THAT THE TOXICITY OF THE CHEMICAL MIXTURE AND THE IDENTITY AND QUANTITY OF THE CHEMICALS RELEASED INTO THE ENVIRONMENT, INCLUDING THEIR PHYSICAL FORM AND CHARACTERISTICS (PARTICLES, DROPLETS, GASES), CAN BE ESTIMATED.

THE AGENCY SHOULD DEVELOP A REVISED DESTRUCTION EFFICIENCY PARADIGM SO THAT ITS ASSESSMENT OF INCINERATOR PERFORMANCE CAN ACCOUNT FOR THE VARIABILITY OF EMISSIONS AND EFFLUENTS.

Chapter 4

MONITORING OF STACK EMISSIONS

Obtaining accurate information on which organic materials exit an incinerator stack depends on the adequacy of quality assurance/quality control procedures in sampling and analyzing stack emissions. These procedures include obtaining representative gas samples, separating and quantitatively storing the sampled organic components, quantitatively retrieving the stored materials, and determining what compounds are present and in what amounts. The accuracy and precision of these steps will determine the confidence in the predictions of both transport, fate and biological effects of the materials that are identified.

To date, the sampling of stack gas emissions has not occurred in a manner which would allow appropriate scientific evaluation. For example, the sampling trains used to collect the organic emissions for analysis were not consistent in either operation or design. As a result, it is difficult, if not impossible, to compare results from the various studies. Often a single sample point in the stack was used to gather the sample for chemical analysis. Vagaries in flow, temperature, and gas composition that can occur within a typical large scale commercial stack require sampling at many locations in the stack to gather a composite of the emissions.

A serious drawback of all the sampling programs carried out during previous incineration research burns is the collection of data for only short durations and under normal or "optimal" operating conditions. During periods of abnormal operating conditions, Agency staff informed the Committee that the sampling probe was removed or that sampling was terminated prematurely when sampling trains became clogged. Such practices lead to inaccurate results. On a few occasions, the Committee questioned whether the sample train was adequately washed with a variety of solvents prior to sampling to remove condensed residues of high molecular weight components and particulate materials. Such practices would, of course, introduce additional inaccuracies.

One of the most notable sources of error was associated with the methods used to calibrate the sampling apparatus for recovery of suspected organic compounds. It appears that some recovery information was collected by spiking the sample train under ambient conditions and not under circumstances that at least simulate actual field conditions. The most obvious of these conditions was a gas stream at high temperature that is enriched with CO, CO_2, H_2O, and HCl. The Committee recognizes that recoveries of organic compounds from various gas streams can be markedly influenced by the inorganic components present, but it believes that the Agency should undertake efforts to develop recovery protocols that at least approach field conditions. EPA can use information obtained from such methods not only to evaluate past analytical information but also to optimize future sampling efforts.

There appears to be a general lack of information on the reproducibility of the sampling processes employed to date. The simple and most direct method to establish the limits of reproducibility consist of conducting multiple samplings of the same stack gas emissions under the same conditions.

Most stack sampling has addressed the problem of measuring the presence of unmodified feed components in the stack gas emissions. In those cases where investigation of combustion by-products occurred, the sampling most often focused on smaller molecules of low polarity. Although such materials are important, they do not address the considerable contribution to the stack gas from polar compounds. The sampling, recovery and analytical methods employed have not recognized these possibilities. The polar by-products, if formed, may be of special toxicological significance because of their increased water solubility.

To calculate mass emission rates of specific compounds, the stack gas temperature and velocity should be measured at the sample points with the results integrated over the stack cross section to determine the mass flow to each component.

Conclusion:

Previous sampling efforts during research burns have occurred either under optimal burn conditions, or through the use of inadequate sampling procedures during upset conditions which occur with unknown frequency. Even relatively short-term operation of incinerators in upset conditions can greatly increase their total loadings to the environment.

RECOMMENDATION:

THE DETERMINATION OF THE ACTUAL EMISSIONS AND EFFLUENTS OF INCINERATORS SHOULD RESULT FROM AN ASSESSMENT OF THE TOTAL MASS LOADING TO THE ENVIRONMENT UNDER ALL OPERATING CONDITIONS.

Conclusion:

The existing analytical data for emissions from hazardous waste incinerators have a variety of limitations. Among the major problems are the limited number of chemicals selected for analyses and the fact that the analytical methodologies have not been validated for either the conditions of the test and for the complex mixtures which exist in incinerator emissions. As a result, no relatively complete and reliable analyses of mass emissions from either land or sea based incinerators exist on which to develop subsequent estimates of the potential for environmental exposures. These analytical problems are particularly difficult to solve for incinerators with very high exit temperatures.

RECOMMENDATION:

SAMPLING AND ANALYTICAL METHODOLOGIES SHOULD BE VALIDATED FOR MEASUREMENTS OF EMISSIONS FROM HAZARDOUS WASTE INCINERATORS.

Chapter 5

ATMOSPHERIC TRANSPORT AND FATE

Source configuration, topography, and ambient meteorology all strongly affect subsequent environmental transport and fate of chemicals. Once emitted, stack gases and particles are transported varying distances through the atmosphere until ultimately they are either destroyed through such mechanisms as photo-decomposition or deposited on land or sea surfaces. Any prediction of the biological impact of incinerator emissions needs to consider these factors.

Atmospheric properties which determine the transport and fate of these emissions are highly variable in space and time. On-shore and off-shore meteorological conditions can differ widely and need to be considered separately. Scientists have a general understanding and documentation of both large-scale weather and climate over coastal seas and water circulation patterns. On the other hand, micro-scale conditions that determine plume dispersion and deposition are less well known, and the available data base is limited to several experimental studies conducted within 10 km off the shoreline of the coasts of Long Island (Raynor et. al., 1975, 1978), Louisiana (Dabberdt et. al., 1982), and south-central California (Zanneti et. al., 1981, and Dabberdt et. al., 1984). In general, better documentation exists for meteorological conditions over land, both on large and small scales.

The behavior of plumes, such as those from incinerators, has undergone extensive study and, with care, can be modeled adequately for the purpose of simulating worst-case or even typical concentrations. Some attempts at simulating concentrations and dosages from land and sea based incinerators exist in the available literature. In one study (O'Donnell et. al., 1982), EPA requested that Oak Ridge National Laboratory determine atmospheric concentrations resulting from several actual incinerators that were then hypothetically located (for modeling purposes) in various U. S. cities. The study authors used a historical weather data base of several years. Although the results may be considered "typical" of what usually happens, they do not depict a range of conditions resulting from local meteorology (e.g., inversion capped valleys) or adverse combinations of source location and demographic distributions. Another EPA-contracted study (JRB Associates, 1984) attempted to evaluate worst case impacts from shipboard incinerator operations 200 km off shore. The meteorological input data used to drive the model, as well as some of the physical assumptions, were questionable at best. Furthermore, the model utilized was not appropriate to conditions involving a moving source and a fixed receptor. Additionally, the final Environmental Impact Statements for the Gulf of Mexico (EPA 1976) and North Atlantic Ocean (EPA 1981) burn sites discuss the atmospheric and oceanic characteristics but do not discuss plume behavior and atmospheric stability in sufficient detail to evaluate the atmospheric dispersion calculations that were presented.

Although limitations to the precision and accuracy of the available over-land and over-water dispersion models exist (Hannati et. al., 1984), analysts can obtain simulations of sufficient accuracy for the purpose of evaluating incineration impacts.[1] The more important uncertainties arise from assumptions of estimates regarding the nature and rate of the effluent emissions, wet and dry deposition rates, meteorological inputs and atmospheric reactions (dry and aqueous).

Important differences in dispersion rates can be achieved over water by selecting the time and place for incineration and varying the navigation of the ship (e.g., cruising across the wind). Atmospheric mixing and transport exhibit strong regional differences in rate and extent, and large changes occur under different seasonal and weather conditions. The North Atlantic Ocean has much better atmospheric conditions for dispersion year round than does the Gulf of Mexico, but the latter exhibits more optimal dispersion conditions in fall than in late winter. Incineration over land should take into consideration the large range of dispersion efficiencies encountered. There will be periods when poor dispersion conditions produce high, local concentrations, and the EPA should consider reducing or eliminating incineration at these times. Agricultural burning is controlled in the western states in an analogous manner.

The Agency has treated the plume rise issue in a cursory manner even though the scientific literature documents that it has an important impact on pollutant transport and removal. Plume rise can be a critical determinant of downwind concentrations by governing whether emissions get trapped below an elevated inversion, embedded in a surface based inversion, or contained above an elevated inversion that the plume has penetrated. The EPA/JRB dispersion analysis (JRB, 1984) assumes a worst case temperature lapse rate for a surface based inversion that is an order of magnitude less than actually observed in Gulf of Mexico dispersion studies (Dabberdt et. al., 1982). Subsequent plume rise considerations are thus unrepresentative. To enhance the credibility of these efforts, EPA should eliminate discrepancies of this type and initiate more rigorous and representative model simulations.

In a number of places, EPA estimates and calculations assume that emissions from incinerator stacks will be deposited in the Gulf of Mexico. Agency staff also implicitly stated this position in some of their briefings to the Committee. In actuality, some of the compounds may have atmospheric lifetimes of weeks or more during summer and fall and may be dispersed over the hemisphere. During these periods, the

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[1] Such model simulations are typically within a factor of three of representative observations.

atmosphere is unstable, and the contaminants will rapidly move through the depth of the mixed layer which frequently is capped by a thermal inversion at a 300 meter (m) to 600 m altitude. However, plume rise of the heated incinerator emissions may be sufficient to penetrate the inversion, effectively isolating the elevated plume from the underlying water surface and leading to long distance transport and dispersion. Should plume rise not reach above the inversion surface, the low atmospheric concentrations in the mixed layer below the inversion will limit deposition.

Meteorological dispersion conditions are different during winter and early spring when Gulf of Mexico surface water temperatures are low (15°C-20°C) and the advection of relatively warm air results in a steep, shallow inversion from the sea surface to heights of 100 m to 250 m. Experimental studies in stable atmospheres over both the western Gulf and the Pacific Ocean (off the coast of south-central California) indicate very small diffusion rates for non-buoyant plumes; for example, the second moment of the vertical concentration profile of gases released at a height of 13 m above the sea surface typically ranges from 26 m to 60 m at a fetch of 8 km from the source, while the second moment of the corresponding horizontal concentration distribution is typically 100 m to 500 m. Thus, concentrations can be high, but the impact area small. The plumes of some ocean based incinerators, however, may have high temperature and high exit velocities. Under these conditions, the plume is dominated by buoyancy factors in its initial stages and may penetrate low level inversions.

Land incinerators with scrubbers have cooler plumes and may not penetrate low level inversions. In addition, local topographic conditions on land have profound influences on air circulation and mixing with subsequent impacts on the fate of the plume. It is important that the Agency examine these different cases in some detail to define more clearly the plume rise and dispersion conditions that will exist.

Plume contact with the sea surface would only occur when the plume either cannot penetrate a surface based or elevated inversion or is entrained by the atmospheric wake in the lee of the ship. The former requires additional calculation using more representative meteorological data already available. The latter (downwash) phenomenon is unlikely, though possible, and should be analyzed more rigorously than has been done to date (only anecdotal arguments have been suggested). Even when the plume touches the sea surface, the small concentrations in a convective atmosphere and the very low diffusivity of the air near the water surface in a stable atmosphere will likely minimize the diffusion of gases into the water or the fallout of particulates. Sorption of organic gases occurs upon cooling, and when attached to particles, the removal rates will accelerate. If the volatile materials are not attached to particles, few of these compounds are likely to deposit in the immediate area of the Gulf of Mexico.

EPA should address the issue of wet deposition in more depth. Precipitation is often an important factor which supplements dry removal and may incorporate soluble compounds by direct contact and scrubbing or by absorbing onto particles of a wide variety upon which water condenses to form cloud drops. Rain drops are formed by the coalescence of millions of cloud drops, each of which initially had a solid nucleus. While rain will quickly remove HCl, other compounds need examination to determine whether they will attach to particles in the air or are efficiently removed by rain.

Conversion processes are also a factor in atmospheric transport. It is likely, for example, that particles will form downwind in the plume as well as in the stack. Photochemical processes will destroy some compounds, while others will remain as gases for long periods, and some disperse into the stratosphere. Those gases with low vapor pressures may condense or adsorb on suspended particles.

EPA did not give sufficient consideration to a few additional atmospheric factors. These concern the separation distance between an incineration vessel and receptors (such as people) and the development of a range of meteorological scenarios. The EPA/JRB (JRB 1984) scenario assumes that the vessel locates at 200 km offshore and that the nearest receptor is at the shoreline. This assumption ignores the consideration of exposure to people on offshore platforms and on other vessels. The EPA/JRB (JRB 1984) worst case, over water analysis assumes a single atmospheric regime: a steady wind into which the incineration vessel cruises continuously at a steady speed and heading (three stability assumptions are given as well). While this is one valid transport regime, others should be considered. One example would involve a calm period (with the ship making a circular or other closed course) followed by a period of on-shore transport for a period followed by a wind reversal with subsequent on-shore transport (in effect, a doubling of the effective emission rate). If negative impacts result, these could be minimized by appropriate movement of the ship or control of the burn period. The latter is especially appropriate to land based incineration.

In addition to the dispersive nature of the atmosphere and the possibility of local direct deposition of stack emissions into the ocean for long periods, one must consider the complexity of ocean circulation. Here, too, there are surface circulations of varying vigor and dimension driven by larger circulations such as the Gulf Stream or the gyres that spin off from such large circulations. The mixed layer of the ocean also reflects winds and convection patterns in the atmosphere. Some of these patterns become well established and are transported by larger scale currents. Thus, a ship moves through these patterns of flow which are, in turn, transported laterally and changing with time. Simultaneously, the incinerator plume discharges into a similarly complex atmospheric circulation. This is likely to result in a very short and erratic exposure of any portion of ocean to a segment of the plume.

The dynamics of the emissions and their potential impacts on biota are exceedingly complex. Unless an adequate baseline of the quantitative and qualitative nature of the emissions and their subsequent fate exists, it is very difficult to design a sampling program which can assess environmental impacts, especially in a marine setting.

Due to the widespread distribution of gaseous effluents from incineration at sea covering millions of square miles of ocean and land and, in fact, the entire globe, one can ask why incineration at sea is any different from incineration anywhere else. It is possible that land incineration can produce as much fallout at sea as would ocean incineration because of the much larger quantities of combusted material emitted over land, including unregulated on-site incineration and municipal incineration. Unless a case can be made that the contaminants quickly attach themselves to very large particles with appreciable fall rates of several centimeters per second, or unless they disperse into rain showers, the local influence of incineration at sea may be negligible at the efficiencies given for the incinerators. If incineration takes place in situations where no rainfall occurs within a few miles, the rain problem becomes insignificant. The key issue is to determine whether the incinerators operate properly and destroy the wastes, and what new compounds, other than those destroyed, exit the stack and are toxic. The Environmental Impact Statement for the designated North Atlantic incineration site (EPA 1981) clearly states that some substances degrade into more toxic materials than the precursors and that others produce new compounds as a result of incineration. (This is also mentioned by Ackerman et. al,. 1978.) EPA should establish the characteristics and quantities of these compounds. If they have negligible environmental consequences, the atmospheric component of incineration at sea activities may be a nonproblem. In fact, the mobility of the ship and the ocean can avoid large accumulations of fallout in any particular area as might occur for a fixed land based incinerator.

Conclusion:

The numerical simulation of atmospheric transport and diffusion processes and the resulting exposures to environmental receptors requires technical improvements and greater delineation of the intended uses of such simulations for over-land and over-water situations. In general, current models have not sufficiently utilized the large existing meteorological data base.

For land based evaluations, the modeling procedures have inadequately considered the local effects of atmospheric circulations (including topographic effects) which can result in poor dispersion of even recirculating conditions. The modeling of emissions also needs to consider upset conditions because the chemical and physical characteristics of the emissions are likely to be different at those times. If, upon further analysis, these compounds exhibit negligible environmental characteristics, atmospheric dispersion of such pollutions may not be a problem.

Over-water simulations also need to take into account the occurrence of upset conditions in a realistic fashion. Because of the incinerator ship's mobility, a Gaussian plume dispersion model is not appropriate for this situation. An unsteady dispersion modeling approach is required to treat the time-variable source location and intensity conditions. The models utilized should be able to accommodate plume rise dynamics, ship wake effects, plume chemistry, and wet and dry deposition. The models should also be capable of incorporating weather changes, changes in ship movements, and unusual emission situations, including catastrophic failures, into the analyses. It should be noted, however, that atmospheric processes over the ocean, such as rainfall patterns, may mitigate the potential impact of incinerator emissions.

RECOMMENDATION:

NUMERICAL SIMULATIONS OF ATMOSPHERIC TRANSPORT AND FATE OF INCINERATOR EMISSIONS ON LAND OR AT SEA SHOULD BE REVISED TO IMPROVE THEIR REALISM. THE ISSUE IS PARTICULARLY ACUTE WITH RESPECT TO MOVING SOURCES.

Conclusion:

Assessing the transport and fate of chemicals released into the environment is a necessary precondition for estimating probable exposures to various organisms and for calculating the potential for adverse effects. EPA should include both the chemical and physical characteristics of emitted compounds in the development of exposure estimates. Calculations can result by direct measurement or by computer simulation coupled with laboratory or field verification. The Committee found that EPA had evaluated these phenomena for land based incinerators essentially on the basis of computer modeling alone with little or no field verification. In the case of ocean based incinerators, the Committee found the field measurements to be largely inadequate.

The problems associated with ascertaining the possible impacts from land based incinerator emissions in the near field ambient environment are not trivial. This is due, in part, to the high ambient chemical concentration levels around such facilities from a variety of sources located in developed areas. To improve the capability to detect and evaluate possible environmental effects, EPA should focus its measurement efforts in those areas which it estimates receive the highest loadings from incinerators. Such measurements can be conducted most readily through the combined use of simulations and spiking of the plume with suitable tracers, such as perfluorocarbons.

RECOMMENDATION:

EPA SHOULD EVALUATE THE ENVIRONMENTAL TRANSPORT AND FATE OF EMITTED SUBSTANCES TO PROVIDE EXPOSURE ASSESSMENT DATA FOR BIOLOGICAL RECEPTORS, INCLUDING HUMANS. SOURCE-RECEPTOR RELATIONSHIPS SHOULD BE QUANTIFIED USING TRACERS AND SIMULATION MODELING TOGETHER WITH AMBIENT GAS AND PARTICULATE CONCENTRATION MEASUREMENTS.

Conclusion:

A very important application of modeling is the identification of optimal locations for alternative incineration sites. The siting evaluations should consider temporal meteorological variations as well as spatial micro-meteorological differences associated with the sites. In this way the Agency could evaluate local, site-specific effects on the dispersion and subsequent exposures to waste incinerator emissions.

RECOMMENDATION:

DECISIONS ON THE SITING AND OPERATION OF HAZARDOUS WASTE INCINERATORS SHOULD CONSIDER LOCAL METEOROLOGICAL CONDITIONS TO MAXIMIZE ATMOSPHERIC DILUTION AND TO AVOID EXCESSIVE AMBIENT CONCENTRATIONS.

Chapter 6

TRANSPORT AND FATE OF INCINERATION PRODUCTS IN AQUATIC SYSTEMS

After emissions from incineration activities at sea or on land reach the atmosphere they are diluted, transformed, and transported in very complex patterns. Various mechanisms, such as strong sorption to particles and/or biomagnification in food webs, may produce locally elevated concentrations of an emitted combustion product. However, the general picture is one of dilution of the emitted compounds, and even the two apparent concentrating mechanisms cited above are dominated by entropy rather than by active transport mechanisms working against a concentration gradient.

The Agency has attempted to model the environmental transport of combustion products. However, most of these models treat the atmospheric or the aqueous compartments as uniform matrices.

The first contact of any combustion product with an aquatic marine or fresh water system occurs at the water surface or near to the surface if scrubber water is injected into the water column. By the time that such contact occurs, the combustion products may experience significant dilution, transport, changes in physical and chemical state, and photodegradation. Contrary to popular perceptions, the properties of the water surface differ significantly from the subsurface properties.

The Surface Microlayer

When combustion products enter water, directly from the atmosphere, the surface layer (also termed the surface microlayer or the surface film) is the area of initial impact. The composition and physical properties of the surface microlayer dictate that it play several roles in aquatic ecosystems: as a site of physio-chemical processes which serve in the transport of materials between air and water; as an intermediary source or sink for airborne organic and inorganic components; and as an important component in food webs. Because the surface microlayer is not part of common knowledge outside the field of oceanography (Bidelman et. al., 1976 and Patil, 1982), it receives somewhat more attention in our report than do other aspects of aquatic ecosystems.

A very thin film of natural organic matter more or less continuously bounds the water surface. This film is visible as the familiar sea "slick" in marine systems and fresh water lakes and results when the film depresses the surface tension of the water sufficiently to damp capillary waves. It is important to recognize, however, that even when no "slick" is visible, an organic film usually bounds the water surface.

The surface film is subject to lateral transport primarily influenced by wind stress rather than water currents. The slick becomes visible upon the convergence of vectors of wind stress, a water surface convergence, or a wind stress vector toward a front. Measurements of film formation rates have recorded changes in surface potential in ocean environments;

within about 20 seconds a clean surface forms a film that reflects a surface potential change of about half its initial values (Van Vleet and Williams, 1983). Microturbulence or bubble transport of surface active materials may double this value within one to two hours. Natural organic materials largely comprise the film which is continuously fractionated into the sea surface. There it is trapped when it exhibits even slight hydrophobicity due to the loss of the energy of hydration. Much of the surface organic matter is particulate, with maxima in the 0.2 um to 1 um range (Henrichs and Williams, in press). In part, this reflects the high concentration of bacteria in the film [10^2 to 10^3 times their concentration in the subsurface water (Harvey, 1979)]. Much of the organic matter may be colloidal (Stumm and Morgan, 1981). The release of amino acids on hydrolysis suggests that much of the organic matter is proteinaceous, and considerable amounts of bound carbohydrate can be detected as probable glycoproteins and glycolipids. Usually only a small fraction, about 5%, is lipid (Henrichs and Williams, in press), although other studies indicate a higher proportion of lipids. The study by Van Vleet and Williams (1980) of the collection efficiency and bias of 14 collecting techniques indicates the problems in obtaining representative samples.

The natural film, when under lateral pressure, folds and flocks. Some speculation exists (Fox, Isaacs, and Corcoran, 1952) that this collapsed film is one source of "marine snow," the flocculate detritus present in marine waters. Most marine zooplankton are filter-feeders and consume this flock in addition to the phytoplankton and microplankton.

The concentration of organic material in the surface layer of marine systems provides the basis for the food web of the neuston, the biota that live in this niche. The possible significance of biota utilizing freshwater surface films is essentially unknown. In marine systems, the organic material rapidly metabolizes by large populations of heterotrophic and mineralizing bacteria, microflagellates and ciliates, as indicated by high concentrations of free amino acids and inorganic nitrogen detected in surface films. Invertebrate larval forms, such as copepodites and veligers, feed on this concentration of particulate organic matter, bacteria, and microplankton (Zaitsev, 1971; Kittredge, personal communication). Above the surface, the ocean-skaters, Halobates, a genus of marine insects, feed on the surface biota, and below, in the water column, fish and other organisms also feed in the surface layer.

The Water Column and Sediment

Below the microlayer, the water column extends to the bottom of the ocean. Investigations have frequently noted the patchiness of both inorganic and organic nutrients in the water column. It is reasonable to assume that, as in the case of the microlayer, increased concentrations of organic nutrients in discrete areas of the water column may result in a parallel partitioning of organic and trace metal contaminants into these patches. The water column is not only the habitat of the pelagic organisms but is also the pathway through which zooplankton migrate in their daily travels between the mesopelagic zone and the surface, and is the highway through which a rain of detritus falls to the bottom. The water column supports, in addition to plankton, a largely non-resident, mobile population of organisms with daily and seasonal activity patterns. These populations transport food away from the source to spatially and temporally distant areas, while zooplankton migrators move materials by vertical migration. Finally, on the bottom of oceanic systems, scientists have suggested for some time that a rain of particles functions as a primary means by which nutritive material reaches organisms at depth (Wiebe et. al., 1976). The major components of this material include fecal pellets (Hinga et. al., 1979), crustacean carapaces, large animal carcasses, large phytoplankton cells (Wiebe et. al., 1976), and inorganic shells of foraminiferans and pteropods with absorbed organic matter, all originating from the surface and the water column below it.

Estimates of the settling rates of organic material from the surface layer are difficult to obtain but may be quite rapid. Sinking rates for fecal pellets occurs within the range of 50 m/day to 940 m/day, and transit times record depths of more than 2000 m in 9 days to 40 days (Wiebe et. al., 1976).

The sediments often play a predominant role in freshwater environments in the migration and storage of hydrophobic materials. The large amounts of organic carbon in freshwater sediments act as major depots for these hydrophobic materials through both sorption and partitioning processes (Neeley, 1980). Considering the mass of sediments and the concentrations of PCBs and common chlorinated pesticides in the water, biota, and sediments of the Great Lakes (Veith et. al., 1977; Haile et. al., 1975), it appears likely that the sediments contain the greatest amounts of these hydrophobic materials in fresh water systems. Documentation exists that PCBs also have contaminated marine sediments at depths of 4 km in the Mediterranean Sea. (Bernhard, 1981).

From the preceding discussion it should be obvious that the surface microlayer does not exist in isolation. Though it functions as the site of entry of atmospheric chemicals into marine ecosystems, it is also closely coupled to events which occur in the bulk phase and in the sediments. Those combustion products which enter the aquatic environment sorb onto particles which descend to the sediment; they will partition into the bulk phase water; and they will become incorporated into biota directly and through food webs. All of these processes can be thought of as competing sinks for the chemicals entering the system; none of these sinks is independent of any of the others.

Food Webs

Biomagnification through food webs is a complex process which depends upon partially understood physical/chemical characteristics and upon interspecies relationhsips in food webs. Compounds which bioconcentrate readily may not necessarily biomagnify. While models exist which can provide rough approximations of the extent of bioconcentration, the ability to project biomagnification is much less reliable.

While the magnification of chemicals in food webs is a very complex process, it can be separated into three component parts. These include 1) the direct uptake of chemicals from water (through cell surfaces, integument, or gills)--"bioconcentration;" 2) the uptake of chemicals through contaminated food, in addition to that which is derived directly from water--"bioaccumulation;" and 3) the uptake of chemicals by all routes in a context of ecological trophic levels--"biomagnificaion." For most organic chemicals the bioconcentration process results from passive diffusion whose driving force is related to the differential solubility of these chemicals in fats relative to water. In this context, the fats compete as a sink against the water bulk phase, against the compounds in the surface microlayer, and against the sorptive potential of suspended particles and of sedimentary particles. Thus, bioconcentration can be thought of as the end result of multiple partitioning processes.

The bioconcentration process relates only indirectly to food webs since it deals only with the direct uptake of chemicals from the ambient environment. Food webs are important when the uptake through food is considered in addition to bioconcentration. When a substance can partition readily between intracellular lipids and water, then bioaccumulation contributes little to the final equilibrium between water and organisms because bioaccumulated material in excess of that which is compatible with the bioconcentration coefficient merely results in a net flux from the organisms to the environment (Hamelink et. al., 1971; Neely, 1980). Even DDT and dieldrin have, on occasion, failed to demonstrate a biomagnification effect in strictly aquatic systems, as demonstrated by finding constant concentrations of these simple pesticides in the fat of several fish species in the Great Lakes, regardless of trophic level (Reinert, 1970). Food web processes become prominent when the compounds have very long residence times. This development is associated with high lipid solubility combined with high molecular weight at low water solubility (Neely, 1980). The driving force, which allows the concentration in the predator to be higher than that of the prey, is not due to any active transport against the concentration gradient in the gut of the predator but to the fact that the digestive process involves a phase change of the lipids of the prey which act as the solvent for the bioaccumulatable substance. This, as a consequence, alters the basis for the partitioning.

<u>Conclusion:</u>

The Committee found that the Agency's evaluations, while appropriately emphasizing the dilution of pollutants, have not effectively addressed mechanisms in the environment which would result in the concentration of emission products. Knowledge of such mechanisms is important to a fuller understanding of pollutant transport and fate even though the general picture is one of dilution of the emitted compounds.

The segments of the biosphere impacted by the emissions from chemical waste incinerators will be largely influenced by the dynamics of atmospheric and aquatic transport processes. Within these processes, mechanisms, such as the following are likely to influence the concentrations which actually impact biota 1) phase separation and chemical distribution between phases, 2) interphase transport at air/water, air/solid, air/biota, water/solid, air/biota, water/biota, and solid/biota interfaces, and 3) photo- and biochemically stimulated reactions involving the incinerator emissions after they leave the stack.

RECOMMENDATION:

THE DYNAMICS OF ENVIRONMENTAL TRANSPORT, INCLUDING CHEMICAL PARTITION BETWEEN PHASES AND INTERPHASE MASS TRANSPORT SHOULD BE EVALUATED IN A WAY THAT IS USEFUL FOR EXPOSURE ASSESSMENT.

Conclusion:

Surface micro-layers may play significant roles in the concentration of some chemical species.

RECOMMENDATION:

EPA SHOULD INCORPORATE THE ROLE OF MICRO-LAYERS IN THE TRANSPORT AND CONCENTRATION OF EMITTED CHEMICALS INTO ITS ANALYSIS.

Conclusions:

Environmental transport and fate processes exhibit both short-term and long-term variability and trends. These changes should influence the Agency's thinking for the selection of the most appropriate averaging time for incineration activities in order to analyze the potential effects of chemical burns.

It is possible to use simulation models appropriately for many aspects of evaluating the environmental transport and fate of emitted chemicals. However, such simulations often have significant limitations which the Agency has not always recognized in its analyses. Such limitations become even more significant when several simulation models are linked into large scale simulations. The results from these large scale simulations are unconvincing, especially when they are not supported by some field validations.

RECOMMENDATION:

MODELING OF INTERPHASE TRANSPORT AND FATE OF CHEMICALS EMITTED FROM INCINERATION SHOULD BE COUPLED WITH SOME FIELD VALIDATIONS.

Conclusion:

Exposures of organisms to chemicals originating from liquid hazardous waste incinerators take place through various pathways which differ according to transport processes and the habits of the organisms involved. Such exposure pathways will certainly include absorption through lungs or gills, skin, and food webs. The exposure will vary over time and in the dose attributable to each chemical. The relative proportions of chemicals in the mixture to which organisms are actually exposed is likely to be different from what was initially emitted by the incinerator because of the differential influences of transport, phase distribution, and chemical reaction dynamics on the emitted chemicals. The accurate determination of exposures, which depends on these many variables, is very difficult. The efforts of the Agency to assess such exposures have been inadequate because they resulted from either individual judgments or computer models without adequate laboratory or field verification.

RECOMMENDATION:

THE AGENCY SHOULD EVALUATE EXPOSURE DURATIONS AND CONCENTRATIONS BASED UPON BOTH A DETAILED ASSESSMENT OF TRANSPORT PROCESSES AND THE HABITS OF THE EXPOSED ORGANISMS.

Conclusion:

Some toxic chemicals have not biomagnified in aquatic systems such as the Great Lakes. When chemicals biomagnify, however, a potential exists for adverse effects on aquatic life and consumers of aquatic life, including humans. Liquid hazardous wastes may contain chemicals which can biomagnify or, when burned in an incinerator, may produce combustion products which biomagnify.

RECOMMENDATION:

EMISSIONS FROM LIQUID HAZARDOUS WASTE INCINERATORS NEED EVALUATION FOR CHEMICALS WHICH CAN BIOMAGNIFY. THE DEVELOPMENT OF METHODS TO IDENTIFY THE POTENTIAL OF CHEMICALS IN INCINERATOR EMISSIONS WHICH CAN BIOMAGNIFY IS NEEDED.

Chapter 7

TRANSPORT AND FATE OF INCINERATION PRODUCTS IN TERRESTRIAL SYSTEMS

Land based hazardous waste incinerators are stationary point sources which emit pollutants into air, land, and water media. Emissions may occur as part of the incineration process, as part of the scrubber operations, or as fugitive emissions. Uptake of emissions by terrestrial life may occur through air, water, soil, or via the food web.

Functional differences between sea and land incineration require distinctive approaches in near-field assessment. These functional differences result from variations in incineration temperatures as well as from treatment of the exhaust gases. Since land based incinerators often have scrubbers and precipitators, the resulting emissions are different, both in quanity and type, from those generated by incinerators which do not have such units. For instance, land based incinerators generate scrubber waters, sediments, and sludges that must be disposed. Their cooler gaseous emissions may result in a different chemical composition relative to the hotter emissions of sea based incinerators. The sampling of exhaust gases is often simpler for land based incinerators.

Land based hazardous waste incinerators tend to be located in developed areas, and it may be difficult to establish causal relationships between residues originating from incineration activities and observed environmental changes. The burning of a wide range of fossil fuels for heating, transportation, and industrial processes, for example, releases by-products of combustion, many of which may have similar physical and chemical characteristics as those compounds emitted by hazardous waste incinerators. Thus, an association of combustion products with environmental degradation is not necessarily proof of a causal relationship with hazardous waste incineration.

It is possible to collect representative samples of gaseous, aqueous, and solid incinerator emissions and effluents to develop a mass balance estimate of what enters the environment. Many commonly accepted techniques also exist for sampling which contaminants enter the terrestrial system. These include air and deposition samples as well as samples of the physical and biological systems into which they enter.

Transport models developed for the dispersion and transport of air pollutants provide a basis for understanding pollutant behavior under a wide range of atmospheric conditions, including the influences of terrain features. Models also exist to track the distribution of pesticides from both ground and aerial application. Modelers have already used some of these techniques to determine deposition from plumes.

Models of plume dispersion from known incineration sources should provide information on appropriate sample sites. Sampling frequency, location, and subsequent stratification of the impacted area, can be determined following initial sampling to calculate concentration gradients. Since routes of input into the ecosystem are important to subsequent transport and accumulation, the development of sampling systems should insure and account for these parameters. These include air, particulate matter, deposition in rain and snow as well as movements in water and in biota. Tracer releases from incinerators (see Chapter 5) would aid in evaluating atmospheric transport routes. The distribution of receptors (human and nonhuman), from near-field/high contamination levels to areas outside the near-field impact area, should also be considered.

Biological and physical sampling systems for both near and far-field deposition should initially derive from plume models and the composition of the physical and biological systems into which the effluent is released. Plants and non-mobile animals, such as soil invertebrates, would provide the best insight into near-field estimates of deposition and accumulation. Evaluation of biomagnification would require sampling of higher trophic levels and would involve more mobile species and greater sampling variance as a result of differing exposures in space and time.

The potential hazard of toxicants to the terrestrial ecosystem depends, in part, upon the physical state of the substance. If the material is water soluble, it will tend to fall upon the vegetation and soil with precipitation. This often means that it will tend to wash off the vegetation and infiltrate the soil, or that it will absorb directly into the plant. In the soil, it will partition between the biota, the soil itself and the downward percolation of water, eventually moving to groundwater. In the soil or in the plant, it may detoxify or pass into the food web and undergo biomagnification.

For most of the known toxicants of concern for land based incineration of chemicals, few data are available upon which to base estimates of this partitioning. Data on the uptake of herbicides from soils will yield some clues to the behavior of other organic molecules in the soil, but only very rough estimates are possible. Many of the toxicants are nearly insoluble and will probably wash out of the atmosphere sorbed onto particulates. Those which deposit on vegetative surfaces may adhere to the cuticular layer in preference to sorption on the particle surface, but this has not been sufficiently studied. Whether these residues adhere to the plant leaves or fall onto the soil surface, some will enter the food web through ingestion by grazing animals. Even in well grazed pastures, much of the vegetation degrades as litter by microorganisms. The toxicants which are only slightly soluble become virtually immobile in the soil and will persist until microorganisms succeed in attacking and breaking down those that can biodegrade. Some chemicals will degrade quickly by soil microorganisms, some will modify slowly, and others will endure for very long periods. Degradation rates strongly depend upon soil moisture and temperature and the occurrence of suitable organisms, and are still far from being adequately modeled.

Some of the pollutants will find their way into lakes and streams directly through the precipitation, but others will enter through sorption on soil particles subject to erosion. Erosion is an inevitable and natural process involving the uppermost surface layer of the soil upon which the sorbed material will reside. It is possible to conceive of fall-out from successive burns concentrating through selective erosion in the sediments at a much higher density than one might expect on an average basis. Erosion models that might be used to illuminate this question exist, but the material brought to the Committee's attention did not show this level of sophistication. In general, the modeling of the fate of toxicants emanating from incinerators has been rudimentary. Though this is a difficult and complex problem, the Agency's past efforts to understand terrestrial transport processes were not thorough.

While terrestrial food webs are as complex as their aquatic counterparts, scientists also have a better understanding of them. To date, the analysis of biomagnification of incineration products relied upon by EPA apparently derived from a relatively simplistic simulation model (Holton et al., 1984) limited to relatively volatile compounds whose biomagnification potential is not particularly prominent. The Committee did not find any systematic field studies with which to compare these simulations.

Conclusion:

It is difficult to associate the burning of hazardous wastes with observed changes in the terrestrial environment because many land based incinerators are sited in highly industrialized areas which have other combustion sources emitting similar compounds. EPA has not made the fullest possible use of existing modeling techniques to evaluate the transport, fate, and effects of incinerator products in terrestrial systems. Thus, subsequent Agency exposure assessments to biota and humans in the ecosystem are unreliable.

RECOMMENDATION:

EPA NEEDS TO EVALUATE THE TRANSPORT AND FATE OF INCINERATOR PRODUCTS IN TERRESTRIAL ECOSYSTEMS BY USING STATE-OF-THE-ART FIELD MONITORING AND LABORATORY EVALUATIONS IN CONJUNCTION WITH IMPROVED SIMULATIONS.

Chapter 8

EFFECTS ON AQUATIC SYSTEMS

Before assessing the effects of combustion derived pollutants on organisms or ecosystems, the characteristics of the toxicants and an evaluation of the extent of exposure to the respective organisms and/or ecosystems must be determined. Appropriate sampling methods in the stack and plume of incinerator facilities should provide a characterization of the pollutants emitted. Plume dispersion modeling and monitoring should predict and confirm the dispersion of chemicals into the atmosphere and suggest the degree of their transfer from the atmospheric to aquatic systems. In either case, the construction and validation of such dispersion models depends upon measuring the toxicants in question in both the atmosphere and in the part of the ecosystem where organism exposures will occur.

The impact of pollutants on ecosystems is, in part, associated with the feeding relationships that govern the transfer of materials through a system, the properties of the medium (whether aquatic or aerial), and the persistence of the pollutant.

Ingestion of contaminated food is an obvious mechanism by which pollutants enter the biosphere and are transported within it. If, for example, a fish eats algae contaminated with a chemical and retains it, the chemical may transfer to fish-eating birds and perhaps to other organisms, including humans.

Pollution can affect the abundance of many organisms, and hence it can indirectly affect the feeding relationships of an ecosystem by causing either a decrease or an increase in the abundance of a particular species or a type of food. While some pollutants have a lifetime as short as a day as they are transformed into harmless substances, others such as DDT and PCBs degrade very slowly.

Effects Methodology

Field measurements are necessary to assess the degree of aquatic organism exposure from incinerator emissions and to determine their impacts. Two existing measurement techniques include 1) chemical monitoring, which can be used to evaluate the extent of environmental contamination; and 2) biological monitoring, which measures the pollutant impact upon aquatic life.

Biological effects monitoring may, in principle, be carried out at any level of biological organization--from the ecosystem and community to the cellular and subcellular levels--by measuring aspects of structure and function. Measurement at higher organizational levels (for example, community and population structure) can provide an assessment of the immediate impact and recovery after an acute pollution incident or the dramatic long-term consequences of high levels of pollution. Although some documentation exists on the fate and effects of specific halogenated hydrocarbons, our understanding of pollution effects on community and ecosystem structure and function is generally insufficient to establish techniques for the early detection of any gradual deterioration or improvement in environmental conditions. The need for sensitive measurements of adverse biological effects of toxicants may be partially met by the structural and functional responses at the organismal, cellular, and subcellular levels of organization.

Sampling in aquatic systems, especially in the ocean, is not an easy task. The distribution and density of biota in the sea vary extremely both in space and time. Organisms are distributed non-randomly in patches. Some organisms migrate vertically on a daily basis and seasonally between shore and open water. Many larval forms, for example, migrate to the beach or to shallow depths during maturation. Given this variability, the probability that spot sampling will provide a representative picture of the resident biota is slight. Indeed, the combined diluting and dispersing effects of winds, currents, and wave action, as well as the effect of a moving vessel, suggest that effective sampling designs will be extremely difficult to achieve.

Given a general understanding of how ecosystems work, any assessment of the effect of possible contaminants depends upon addressing two major problems: 1) determining the bioavailability and toxicity of the possible contaminants, and 2) the use of sampling to measure effects.

Effects Found to Date.

Attempts have been made to measure environmental effects during some of the research and demonstration burns at sea. One of the studies noted effects. In March 1977, fish (Fundulus grandis) were caged in P-BOMs and exposed to stack emissions from the Vulcanus II which reached the water surface at the ocean incineration site in the Gulf of Mexico. Subsequent analyses of the livers from the exposed fish found significantly elevated levels of cytochrome P-450 relative to controls (Pequegant et. al., 1980), suggesting a response to the exposure. In the laboratory, the induced levels of cytochrome P-450 returned to normal levels. Further investigation of these findings did not occur, and thus, the ecological significance or adverse nature of this response remains uncertain.

Conclusion:

Insufficient techniques exist to detect any gradual deterioration or improvement in environmental quality for aquatic communities or systems. However, laboratory studies of the acute, subacute, and chronic toxicities of combustion products and fractions of combustion products in surrogate and resident species are well within existing capabilities.

Such tests, though limited in their direct applicability to aquatic systems, do provide information on the relative toxicity of emitted compounds. In addition, the capability exists to measure and to assess pollutant effects, particularly short-term effects, on segments of the aquatic ecosystem such as organisms residing in the surface microlayer.

RECOMMENDATION:

EPA SHOULD CONSIDER TESTING INCINERATION PRODUCTS AND MIXTURES FOR THEIR TOXICITY UPON SURROGATE AND RESIDENT SPECIES UNDER CONTROLLED LABORATORY CONDITIONS. IT SHOULD ASSESS THE IMPACTS OF INCINERATION PRODUCTS ON ORGANISMS INITIMATELY ASSOCIATED WITH THE SURFACE MICROLAYER.

Conclusion:

Comprehensive assessments of the impact of changes in aquatic populations on an ecosystem require long-term observations at specific sites. In this instance, particular attention should be given to sampling design and statistical determinations of appropriate sample size.

RECOMMENDATION:

BECAUSE OF THE DIFFICULTIES IN ASSESSING CHRONIC EFFECTS ON THE MARINE ECOSYSTEM, THE TASK OF UNDERSTANDING SUCH EFFECTS NEEDS TO RECEIVE IMMEDIATE RESEARCH ATTENTION.

Conclusion:

The assessment of biological and ecological effects of incineration products constitutes a very complex undertaking. It does not make sense to rely exclusively on laboratory studies, partial field studies, or complex field studies alone.

RECOMMENDATION:

THE ASSESSMENT OF THE POTENTIAL EFFECTS OF INCINERATION PRODUCTS REQUIRES A COORDINATED APOROACH INVOLVING BOTH LABORATORY TOXICITY STUDIES AND FIELD ASSESSMENTS. THE AGENCY SHOULD COUPLE THESE INVESTIGATIONS IN A RESEARCH STRATEGY WHICH PAYS ATTENTION TO BOTH SHORT-TERM AND LONG-TERM EFFECTS.

Conclusion:

The Committee found no documentation that the operation of liquid hazardous waste incinerators at sea has produced acute adverse ecological effects. However, monitoring programs used to date were few and narrow in scope.

RECOMMENDATION:

Appropriately designed field studies are needed to provide assurance that the long-term operation of incinerators does not produce significant adverse effects to the environment.

Chapter 9

EFFECTS ON TERRESTRIAL SYSTEMS

The information presented to the Committee indicates that the Agency has concerns about human exposures to selected compounds which may be emitted from incinerators and absorbed from air, drinking water, and food. Evaluations of potential effects on wildlife, plants, and terrestrial ecosystems appear to be lacking. Data on the toxicities of selected emitted mixtures likewise do not exist.

The Committee received no reports on combustion products deposited in the surroundings of land based incinerator sites, nor any reports of ecological surveys of plant and animal life adjacent to such sites. All assessments were based on relatively simple computer simulations of exposure, without some field validation.

Assessments of Potential Health Effects

The assessments of the potential impacts of emitted compounds on human health have resulted largely from simulations which produced projections of ground level air pollutant concentrations. The scientific community has given wide acceptance to employing the various dispersion models in the preparation of other air pollution assessments. However, exposures of humans are expected to occur also through ingestion as well as through the inhalation pathway. Exposures through food may be particularly important for compounds with low water solubility and high lipid solubility. A draft report by Holton et. al., (1984) hints at the potential significance of food chain effects, even for compounds of much lower molecular weight and lower lipid solubility than are known to occur among the combustion products. This relatively simple model estimates that food would contribute 76% to 83% of the total dose of carbon tetrachloride delivered to humans from atmospheric releases of this compound. On the basis of the data utilized in the model, one would predict a much higher contribution through the food route for compounds such as highly chlorinated PCBs.

While it may be interesting to use the Holton model to evaluate the possible human doses from combustion products of higher molecular weights, the primary utility of such a model seems to be that of screening the exposures which might result from incineration activities at a number of sites. To date, the Agency has placed excessive reliance on such simulations without validating predicted concentrations with actual ambient concentrations, nor has it adequately addressed the effects of local topography on the model. This becomes especially important in the case of the multiple pathway model. Because of the very nature of a multiple pathway problem, this model consists of a number of coupled simulations, each of which contains many simplifying assumptions. Such assumptions invariably introduce errors into the predictions made by the model and, at this time, it is not possible to conclude how such errors propagate in the model relative to the actual processes in the real world.

In the current assessment of potential impacts of incineration emissions, the concentrations projected by the simulations are compared to existing standards or criteria for the protection of human health. Such standards and criteria usually embody sizable margins of safety to protect human health.

Effects on Terrestrial Ecosystems vs. Human Responses

The general public usually assumes that environmental standards providing adequate protection to human populations also afford sufficient protection to the ecosystem and wildlife populations. However, such assumptions have no scientific rationale. The reproductive physiology of birds and some groups of mammals (e.g., the family Mustelidae) appear to be sufficiently different from the commonly tested laboratory animals and humans so that safety evaluations for these groups of animals are often inadequate. Also, many predators occupy much higher positions in food webs than do humans and, consequently, the biomagnification of some pollutants can be much more detrimental for top predators than that predicted for humans. Protection of human health provides no assurance that all plant communities will receive adequate protection, and yet humans ultimately depend upon the productivity of ecosystems. The data required to assure the protection of human health will not automatically provide us with insights concerning the protection of terrestrial ecosystems.

Approaches to the Measurement of Effects

When seeking to evaluate the potential of emissions from incinerators to produce adverse human and ecological effects, three approaches, each of which has limitations, could be tried. These include:

1. The Agency could model the risks from exposure to mixtures on the basis of qualitative and quantitative measurements of the components of emissions, the known toxicities on their quantitative structure/activity relationships, and the application of appropriate interaction models. At the present time, however, the data do not exist to input to such a model. In addition, existing models for evaluating potential risks from single compounds are largely unverified. Modeling of the potential toxicity of mixtures is still in its infancy, and modeling of potential effects on ecosystems, outside the area of bioconcentration, needs even more work. Thus, the prime utility of modeling for this problem is as a rough screening tool to define degree of hazard.

2. EPA could test the toxicity of incineration emissions under controlled laboratory conditions. This type of test is also unlikely to provide definitive answers for a number of reasons. The testing usually occurs with surrogate or representative species either as individuals or in small groups. Also, such tests do not readily lead to examining effects at the population or ecosystem levels. Each mixture requires individual testing until one has developed a picture of the variability in responses due to changes in the mixture. Finally, one must consider the uncertainities of extrapolating test results using models that are difficult to verify. However, carrying out laboratory tests in concert with field studies can have some utility in assessing the potential for

adverse effects. Detection of subtle effects can have significant consequences to individuals and populations. Effects on behavior and on physiological functions often occur at exposures that are significantly lower than those producing acute observable effects. However, there exist a multitude of possible subtle effects, and unless one is sufficiently astute or lucky to design a specific experiment which can detect these biological nuances, they are easily overlooked.

Acute effects are readily observed with relatively simple protocols. The ratio between exposure concentrations found in controlled laboratory tests which produce acute effects, and those which produce no measured effects, even after exposures lasting a life-time, is rarely greater 1000 fold (NAS, 1972; McNamara, 1976; Weil et al., 1969). Thus, if a study reports no acute effects under exaggerated exposure conditions in the various media of concern (e.g., water, soil, air, microlayer, etc.), and the longer term exposure concentrations after initial dilution are much less than 1/1000 of the concentration producing no acute effects, it becomes much more likely that no environmental effects will occur or that they will prove very subtle.

The procedures currently available for sampling incineration emissions are likely to yield a different mix of compounds than those found at some distance from the source. In spite of the shortcomings of this approach, it holds promise in testing actual mixtures. Methodologies exist which scientists have used to test diesel exhaust emissions in mammals (NAS, 1981) and outboard motor exhaust emissions in fish (Brenniman et al., 1976). Studies of this type can give an indication of relative toxicity when they are employed in a comparative mode. They have some, but limited, utility in predicting actual ecosystem level effects.

3. The EPA could undertake to study the alterations of ecosystems or their components directly. Such studies can be very complex, even for measurements of relatively acute effects that might occur shortly after the exposure took place. If scientists can study the responses of the system over longer durations, for marine systems in particular, there is an accompanying need to develop baseline information. Land based incinerators present more manageable problems than sea based combustion units because the terrestrial environment is more easily sampled and more background information exists.

Presently, computer simulations exist of possible risks to humans from inhaled emissions in addition to possible hazards from the food web. However, the Committee has seen no field verifications of the computer predictions or toxicity tests for emissions from large scale land incinerators that are located in environments already heavily disturbed by human activites. It may be impossible and/or irrelevant to look for subtle ecological effects in such areas except for those related to contamination of the human food supply especially via bioconcentrative mechanisms.

Conclusion:

The toxicities of emissions and effluents from land based incinerators are largely unknown.

RECOMMENDATION:

THE TOXICITIES OF REPRESENTATIVE EMISSIONS AND EFFLUENTS FROM INCINERATORS SHOULD BE TESTED, AT A MINIMUM, IN SENSITIVE LIFE STAGES OF REPRESENTATIVE TERRESTRIAL VERTEBRATES, INVERTEBRATES, AND PLANTS OF ECOLOGICAL IMPORTANCE.

Conclusion:

The Committee found no documentation that the operation of liquid hazardous waste incinerators on land has produced significant adverse ecological effects. However, monitoring programs were few and narrow in scope.

RECOMMENDATION:

APPROPRIATELY AMBIENT AEROMETRIC AND EFFECTS MONITORING IS NEEDED TO PROVIDE ASSURANCE THAT THE LONG-TERM OPERATION OF INCINERATORS DOES NOT PRODUCE SIGNIFICANT ADVERSE ECOLOGICAL EFFECTS.

Conclusion:

The Committee has received no documentation that any significant health hazard exists as the result of exposures to the products of incinerating toxic wastes. However, monitoring programs were few and narrow in scope.

RECOMMENDATION:

THE POSSIBLE LONG-TERM CONSEQUENCES TO HUMAN HEALTH OF A CONTINUING PROGRAM OF INCINERATION NEEDS EVALUATION.

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Charge to the Environmental Effects, Transport and Fate Committee on Incineration of Hazardous Wastes

At the October 13, 1983 meeting of the Executive Committee of the Science Advisory Board the Administrator formally requested that the Board assist the Agency in the scientific assessment of environmental impacts associated with the incineration of hazardous wastes at sea. The Executive Committee accepted this request and assigned the responsibility for carrying out this review to its Environmental Effects, Transport and Fate Committee.

At the Executive Committee meeting on April 12, 1984, the Deputy Administrator asked the Committee to also examine the environmental impacts associated with land based incineration of liquid hazardous wastes, and to make a generic comparison of scientific issues between land based and ocean based incineration. The Committee accepted this additional request. The Environmental Effects, Transport & Fate Committee will expand its review and will address the six issues listed below.

The following have been identified as issues the Committee should consider in evaluating incineration of hazardous wastes at sea. The Committee should advise if the Agency has considered and interpreted in a scientifically adequate manner the appropriate data for each area.

1) Transfer of wastes.

What are the various handling, loading, transportation, and routing problems? What potentials exist for collisions, explosions, and spills? Should the Agency develop worst-case scenarios to evaluate the potential impacts of accidental discharges?

2) Combustion and Incineration Processes.

Is the efficiency of destruction properly addressed? Are the quantitative and qualitative characteristics of the combustion products released into the environment appropriately evaluated?

3) Stack and Plume Sampling.

What specialized sampling protocols are needed to adequately characterize representative emissions from the stack exhaust and plume?

4) Environmental Transport and Fate Processes.

How should known and modeled atmospheric and oceanic circulations at the burn sites be considered? Are potential food web influences adequately assessed?

5) Biological Effects.

Do data on incineration efficiency, composition of emission products, and environmental transport and fate processes provide an adequate basis for evaluating biological effects? Have other issues, such as the bioavailability and toxicity of emitted compounds, been adequately addressed?

6) Research Needs.

What key scientific issues should the Agency address in its incineration research strategy?

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SCIENCE ADVISORY BOARD

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Ann Arbor, MI 48109

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Science Advisory Board
U.S. Environmental Protection
Agency
Washington, D.C. 20460

Dr. Douglas B. Seba
Executive Secretary
Environmental Effects, Transport
and Fate Committee
Science Advisory Board
U.S. Environmental Protection
Agency
Washington, D.C. 20460

Members/Consultants

Dr. Martin Alexander
Professor
Department of Agronomy
Cornell University
Ithaca, NY 14853

Mr. Italo Carcich
Bureau of Water Research
New York Department of
Environmental Conservation
Albany, New York 12233

Dr. Melbourne R. Carriker
Professor of Marine Science
College of Marine Studies
University of Delaware
Lewes, DE 19958

Mr. Allen Cywin*
1126 Arcturus Lane
Alexandria, VA 22308

Dr. Walter Dabberdt
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. Kenneth Dickson
North Texas State University
Institute of Applied Sciences
Denton, TX 76203-3078

Dr. Wilford R. Gardner
Head, Department of Soils,
Water and Engineering
University of Arizona
Tucson, AZ 85721

Mr. George Green*
Public Service Company of
Colorado
Post Office Box 840, Room 820
Denver, CO 80202

* Representative of SAB Environmental Engineering Committee

Dr. Leonard Greenfield
1221 Columbus Boulevard
Coral Gables, FL 33134

Dr. George Hidy*
Desert Research Institute
7010 Dandine Boulevard
Reno, NV 89512

Dr. Charles Hosler
Penn. State University
Professor of Meterology
College of Earth & Mineral Sciences
University Park, PA 16802

Dr. Robert Huggett
College of William and Mary
Chairman, Department of Chemical Oceanography
Virginia Institute of Marine Science
Gloucester Point, VA 23062

Dr. Kenneth Jenkins
Professor of Biology
California State University at Long Beach
Long Beach, CA 90804

Dr. Elizabeth Kay
Department of Zoology
University of Hawaii
Honolulu, Hawaii 96822

Dr. James Kittredge
University of Southern California
Marine and Freshwater Biomedical Center
Terminal Island, CA 90731

Dr. John Laseter
Environmental Clinical Lab
3660 Gentilly Boulevard
New Orleans, LA 70122

Dr. John Neuhold
Department of Wildlife Sciences
College of Natural Resources
Utah State University
Logan, Utah 84322

Dr. Charles Norwood
4958 Escobedo Drive
Woodland Hill, CA 91364

Dr. Bernard Patten
Professor
Department of Zoology
University of Georgia
Athens, GA 30602

Dr. Tony Peterle
Department of Zoology
Ohio State University
Columbus, OH 43210

Dr. James Porter*
C/O E31
Post Office Box 215
East Cambridge, MA 02141

* Representative of SAB Environmental Engineering Committee

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